PB85-197358

# Aerial Photography and Ground Verification at Power Plant Sites Wisconsin Power Plant Impact Study

Wisconsin Univ.-Madison

Prepared for

Environmental Research Lab.-Duluth, MN

Apr 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-197358

EPA/600/3-85/034
April 1985

# AERIAL PHOTOGRAPHY AND GROUND VERIFICATION AT POWER PLANT SITES

## Wisconsin Power Plant Impact Study

by

Sarah L. Wynn
and Ralph W. Kiefer
Civil and Environmental Engineering
University of Wisconsin-Madison
Madison, Wisconsin 53706

Grant No. R803971

Project Officer

Gary E. Glass
Environmental Research Laboratory-Duluth
Duluth, Minnesota

This study was conducted in cooperation with
Wisconsin Power and Light Company,
Madison Gas and Electric Company,
Wisconsin Public Service Corporation,
Wisconsin Public Service Commission,
and Wisconsin Department of Natural Resources

ENVIRONMENTAL RESEARCH LABORATORY-DULUTH
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
DULUTH, MINNESOTA 55804

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA/600/3-85/034 | 2. | 3. RECIPIENT'S ACCESSION NO.<br>PB85 197358/AS |
| 4. TITLE AND SUBTITLE<br>Aerial Photography and Ground Verification at Power Plant Sites: Wisconsin Power Plant Impact Study | | 5. REPORT DATE<br>April 1985<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>S. L. Wynn and R. W. Kiefer | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Civil and Environmental Engineering<br>University of Wisconsin-Madison<br>Madison, Wisconsin 53706 | | 10. PROGRAM ELEMENT NO.<br>11. CONTRACT/GRANT NO.<br>803971 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Environmental Research Laboratory<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Duluth, Minnesota 55804 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>14. SPONSORING AGENCY CODE<br>EPA/600/03<br>600/3 |
| 15. SUPPLEMENTARY NOTES | | |

16. ABSTRACT

This study demonstrated and evaluated nine methods for monitoring the deterioration of a large wetland on the site of a newly-constructed coal-fired power plant in Columbia County, Wisconsin. Four of the nine methods used data from ground sampling; two were remote sensing methods without ground verification; and three were remote sensing methods which either used ground verification or relied on the analyst's "on-the-ground" knowledge of the area.

These methods were evaluated on the basis of whether they monitor change at a species or a community level, whether they monitor community change in terms of area or location or both, and whether they provide information about trends in plant communities. They were also evaluated in terms of time, cost, sensitivity, and reliability. Changes in the wetland over a 3-year period are presented, as determined by each of the methods. Eight appendices provide information and raw data for several of the methods, color/texture keys for interpreting airphotos, and an annotated bibliography on remote sensing methods.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| | | |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>Release to public | 19. SECURITY CLASS *(This Report)*<br>Unclassified | 21. NO. OF PAGES<br>292 |
| | 20. SECURITY CLASS *(This page)*<br>Unclassifiee | 22. PRICE |

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

# NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# FOREWORD

The U.S. Environmental Protection Agency was established as a focus of scientific, governmental, and public efforts to improve the quality of the environment. These efforts require expansion of our understanding of the mechanisms that govern environmental changes and in particular those changes that result from our own manimpulations of the environment. One specific thrust of these efforts must be the continous development of more effective and more efficient methods for analyzing the environment and the changes occurring in it.

One such project, which the Environmental Protection Agency is supporting through its Environmental Research Laboratory in Duluth, Minnesota, is the study "The Impacts of Coal-Fired Power Plants on the Environment." The Columbia Generating Station, a coal-fired power plant near Portage, Wis., has been the focus of all field observations. This interdisciplinary study, involving investigators and experiments from many academic departments at the University of Wisconsin, is being carried out by the Water Resources Center and Institute for Environmental Studies at the University of Wisconsin-Madison. Several utilities and state agencies are cooperating in the study: Wisconsin Power and Light Company, Madison Gas and Electric Company, Wisconsin Public Service Corporation, Wisconsin Public Service Commission, and Wisconsin Department of Natural Resources.

This investigation demonstrated and evaluated nine methods of documenting the deterioration of the wetland within the power plant site over a period of 3 yr. Four methods--diversity index, subjective classification, association analysis and structure analysis--used ground sampling methods. Two methods--airphoto monitoring and disturbance mapping --used airphoto data only, while airphoto grid analysis and airphoto interpreted vegetation mapping used airphoto and ground sampling data. Computer assisted mapping used only airphoto data but relied heavily on the analyst's "on-the-ground" knowledge.

Norbert A. Jaworski
Director
Environmental Research Laboratory-Duluth
Duluth, Minnesota

# ABSTRACT

This study was part of a large Environmental Protection Agency study designed to monitor the impacts of the construction and operation of a coal-fired power plant located near Portage, Wisconsin. This study demonstrated and evaluated nine methods used to document the deterioration over 3-yr period of a large wetland located within the power plant site. Four of the nine methods (diversity index, subjective classification, association analysis, and structure analysis) used ground sampling data. Two methods, airphoto monitoring and disturbance mapping, used airphoto data only, while airphoto grid analysis and airphoto interpreted vegetation mapping used airphoto and ground sampling data. The ninth method, computer assisted mapping, used only airphoto data but relied heavily on the analyst's "on-the-ground" knowledge of the area.

These methods were evaluated on the basis of whether they monitor vegetation change at a species or community level, whether or not they monitor community change in terms of area and/or location, and whether or not they provide information about community trends. These methods also were evaluated for time, cost, sensitivity and reliability.

Of the nine methods, only the diversity index, a ground sampling data method, documented species change with time. The other three ground sampling data classification methods dealt with community change, and documented that change by analysis of species appearance and disappearance.

All methods, other than the diversity index, documented changes in vegetation community area and/or location. The ground sampling methods showed point locations of communities which were mapped and quantified changes in relative percentages of sampling points classified as a particular class. Subjective classification is the most sensitive and the most expensive of the three ground sampling methods; vegetation structure analysis is least sensitive and least expensive while the association analysis handles large quantities of data better than either of the other two.

Airphoto methods can better document community area and location changes than can ground sampling data methods. Airphoto monitoring, a purely descriptive method, is the least effective of the airphoto methods, offering only a series of airphotos as a record of change. It does offer the advantage of not requiring any ground verification nor does disturbance mapping. Disturbance mapping, a low cost method, uses a series of maps to record change. Its greatest disadvantage is that it delineates only three

classes--disturbed and undisturbed vegetation and open water. However, in defining only three classes, an exceptionally understandable visual record of change taking place is created.

Airphoto grid analysis, the second most costly method, records percentage cover of vegetation classes on a cell by cell basis. This method documents percent changes in community area but does not directly document changes in community location.

Airphoto interpreted vegetation mapping, the most costly method, was used to map the greatest number of vegetation classes of all the methods. A series of photo-interpreted vegetation maps documents changes in community location and area. Relative percent cover changes can be quantified using either a planimeter or overlaying maps with a grid and counting cells of each vegetation type.

Computer-assisted mapping, the third most expensive method, generates computer quantified vegetation maps. If vegetation classes can be correctly defined and identified during training set selection, this is the most reliable (consistent) of the quantitative cover estimation methods. This method also demonstrates changes in community location. The color film products which can be made using this method provide the best visual documentation of change of any of the nine methods. If the vegetation classes being mapping are reliably identified, this method definitely warrants its high cost.

In this particular study where the user of the information collected and analyzed is the Environmental Protection Agency, it is recommended that the following combination of methods are the most efficient, sensitive and reliable to study wetland vegetation change.

Association analysis (using presence-absence data) should be used to analyze data collected over time to demonstrate the manner in which vegetation communities are changing, year to year. If the equipment and package of programs necessary to use computer assisted mapping are available, this method should be used to quantify change in community area and to demonstrate change in community location. If the computer assisted mapping method can not be used, airphoto interpreted vegetation mapping to supply community locations and area information is recommended.

# CONTENTS

Foreword........................................................ iii
Abstract........................................................ iv
Figures......................................................... vii
Tables.......................................................... x

1. Introduction................................................. 1
   Impacts of plant construction and operation on the study site..... 5
2. Conclusions.................................................. 12
3. Recommendations.............................................. 14
4. Materials and Methods........................................ 16
   Ground sampling data collection.............................. 16
   Airphoto data collection..................................... 19
   Monitoring vegetation using ground sampling data............. 19
   Use of airphotos to monitor change........................... 42
   Monitoring vegetation change with airphoto and ground sampling data...... 67
   Generating computer assisted vegetation maps................. 93
5. Results...................................................... 129
   Method efficiency............................................ 142
   Method sensitivity and reliability........................... 143
   The ground sampling data methods............................. 145
   Airphoto data only methods................................... 147
   Airphoto grid analysis, airphoto interpreted vegetation mapping and computer assisted mapping........ 149
6. Discussion................................................... 153
   Using methods together....................................... 154

References...................................................... 156

Appendices

A. Species Code List............................................ 160
B. Station and Transect Numbers................................. 162
C. Diversity Index.............................................. 163
D. Subjective Classification.................................... 165
E. Association Analysis......................................... 166
F. Airphoto Interpretation Keys for Airphoto Grid Assessment..... 167
G. Airphoto Interpretation Keys for Vegetation Mapping........... 170
H. Annotated Bibliography....................................... 174

# FIGURES

Figure Page

1 Columbia Generating Station site.............................. 2

2 Vegetation map of site.................................... 3

3 Groundwater contours...................................... 4

4 Groundwater movement through the site before and after construction of cooling lake.......................... 6

5 Time line of construction events at the Columbia Generating Station site.............................................. 7

6 Groundwater isotherms at various depths and distances from the cooling lake dike.................................... 8

7 Wetland water level fluctuations.......................... 9

8 Colorinfrared airphoto of study site on July 24, 1976.......... 17

9 Subjective classification of the ground sampling data.......... 30

10 Dendrogram of ground sampling data by association analysis..... 32

11 Association analysis of the ground sampling data.............. 36

12 CIR airphoto used to determine airphoto grid size on October 3, 1977................................................. 44

13 CIR airphoto on June 4, 1972.................................. 46

14 CIR airphoto on July 31, 1974................................. 47

15 CIR airphoto on September 25, 1975............................ 48

16 CIR airphoto on July 14, 1976................................. 50

17 CIR airphoto on September 24, 1976............................ 51

18 CIR airphoto on June 25, 1977................................. 52

| Figure | | Page |
|---|---|---|
| 19 | Color airphoto on June 25, 1977 | 53 |
| 20 | CIR airphoto on October 3, 1977 | 54 |
| 21 | Color airphoto on March 1, 1975 | 55 |
| 22 | Color airphoto on March 1, 1976 | 56 |
| 23 | Color airphoto on March 1, 1977 | 57 |
| 24 | Disturbance map on September 25, 1975 | 60 |
| 25 | Disturbance map on September 24, 1976 | 61 |
| 26 | Disturbance map on June 25, 1977 | 62 |
| 27 | Disturbance map on October 3, 1977 | 63 |
| 28 | Disturbance map on March 1, 1975 | 64 |
| 29 | Disturbance map on March 1, 1976 | 65 |
| 30 | Disturbance map on March 1, 1977 | 66 |
| 31 | Mylar overlay locating transects and sampling stations | 69 |
| 32 | Photo interpreted vegetation map on June 4, 1972 | 81 |
| 33 | Photo interpreted vegetation map on July 31, 1974 | 82 |
| 34 | Photo interpreted vegetation map on September 25, 1975 | 83 |
| 35 | Photo interpreted vegetation map on July 24, 1976 | 85 |
| 36 | Photo interpreted vegetation map on September 24, 1976 | 86 |
| 37 | Photo interpreted vegetation map on June 25, 1977 | 87 |
| 38 | Photo interpreted vegetation map on June 15, 1977 | 88 |
| 39 | Photo interpreted vegetation map on October 3, 1977 | 89 |
| 40 | Spot densitometer | 94 |
| 41 | Two types of scanning microdensitometers | 96 |
| 42 | D-log E curves | 97 |

Figure Page

43 Output from program DLOGE.................................. 99

44 Density to log exposure correction using program CORRECT....... 100

45 D-log E curves generated by program CORRECT.................... 101

46 Overprinted 10-level density slice............................ 104

47 A 36-level density slice....................................... 105

48 Listing provided by program TRAIN.............................. 106

49 Bar diagrams generated by program CLASSBAR..................... 108

50 Histograms created by program HSGRAM........................... 109

51 Scatter diagram created by program SCATTER..................... 110

52 Output from program CLEANTR.................................... 111

53 Percentage matrix from program CLSTRN.......................... 113

54 Output from program BOX4....................................... 114

55 Portion of printed out parallelepiped classification created from program BOX4.......................................... 115

56 How a decision region can be broken into rectangles whose borders closely describe the training set distribution......... 116

57 Portion of a maximum likelihood classification of the site..... 117

58 Probability values plotted on a three-dimensional graph of a scatter diagram............................................ 119

59 Portion of a classification of the site using program TABCLASS...................................................... 120

60 Computer assisted map made from CIR airphoto on September 15, 1975............................................ 121

61 Computer assisted map made from CIR airphoto on July 14, 1976.......................................................... 121

62 Computer assisted map made from CIR airphoto on June 25, 1977.......................................................... 122

63 Computer assisted map made from color airphoto on June 25, 1977.......................................................... 122

## TABLES

| Table | | Page |
|---|---|---|
| 1 | Example of Encoded Ground Sampling Data and the Scheme with which They Were Coded.................................... | 18 |
| 2 | Columbia Generating Station Airphotos......................... | 20 |
| 3 | Diversity Index............................................... | 23 |
| 4 | Summary of Subjective Classification.......................... | 26 |
| 5 | Reclassification of Ground Sampling Data Using Subjective Classification................................................. | 27 |
| 6 | Results of Chi Square Test on Classification Results.......... | 28 |
| 7 | Visually Dominant Species Used in the Association Analysis..... | 33 |
| 8 | Summary of Association Analysis Results....................... | 34 |
| 9 | Reclassification of Ground Sampling Data Using Association Analysis....................................................... | 35 |
| 10 | Summary of Vegetation Structure Analysis Results.............. | 38 |
| 11 | Reclassification of Ground Sampling Data Using Vegetation Structure Analysis............................................ | 39 |
| 12 | Sampling Stations Changing Their Classification............... | 41 |
| 13 | Airphotos Used to Generate Disturbance Maps................... | 58 |
| 14 | List of Airphotos Used in Airphoto Grid Assessment............ | 68 |
| 15 | Vegetation Classes Identified Using Airphoto Grid Analysis..... | 70 |
| 16 | Classes Originally Used to Sum Grid Analysis Data............. | 72 |
| 17 | Grid Analysis Percent Cover Data.............................. | 73 |
| 18 | Chi Square Tests on Grid Analysis Data........................ | 74 |

Table Page

19 List of Airphotos Used to Generate Airphoto Interpreted Vegetation Maps........ 75

20 Vegetation Classes Discernible on Photo Interpreted Vegetation Maps........ 76

21 Ease with which Vegetation Classes Could Be Identified on Airphotos........ 77

22 Relative Percentage Cover of Each Vegetation Class Defined Using Airphoto Interpreted Vegetation Mapping........ 78

23 Vegetation Classes Used to Summarize Airphoto Interpreted Vegetation Maps........ 80

24 Comparison of Percent Cover Results Using Airphoto Grid Analysis and Airphoto Interpreted Vegetation Mapping........ 91

25 Vegetation Classes Derived Using Computer Assisted Mapping..... 92

26 Vegetation Classes Used to Summarize Computer Assisted Mapping........ 125

27 Color and Exposure Values Assigned to Vegetation Classes Identified Using Computer Assisted Mapping........ 125

28 Vegetation Classes Identified Using the Eight Classification and Mapping Methods........ 130

29 Expertise Needed to Use Each Method........ 131

30 Capital Equipment Costs for Photographic Data Collection....... 131

31 Data Collection Materials Cost for One Data Set........ 132

32 Capital Equipment Used with the Nine Methods........ 132

33 Capital Equipment Costs for Data Analysis........ 132

34 Data Processing Materials Costs for One Data Set........ 133

35 Time For Data Collection and Analysis for a 33.5 Ha Site....... 134

36 Time for Collection and Analysis for One Data Set Using Each of the Nine Methods........ 135

37 A Breakdown of Data Collection and Processing Costs and Labor Costs for One Set and Four Sets of Data for a 33.5 Hectare Study Site........ 136

Table Page

38 Data Collection and Processing and Labor Costs for One Data Set and Four Sets for a 33.5 Ha Site.......................... 139

39 Combined Time-Cost (Efficiency) Rating for Each Method......... 139

40 Method Sensitivity Rating Based on Vegetation Classes and Data Type.................................................. 140

41 Method Reliability Based on Data Collection Repeatability, Data Analyst Interaction, and Quantitative or Qualitative Results.................................................... 141

A-1 Species Code List............................................ 160
B-1 Station and Transect Numbers................................. 162
C-1 Diversity Index.............................................. 163
D-1 Subjective Classification.................................... 165
E-1 Association Analysis......................................... 166
F-1 Airphoto Interpretation Keys For Airphoto Grid Assessment...... 167
G-1 Airphoto Interpretation Keys For Vegetation Mapping............ 170

# SECTION 1

# INTRODUCTION

The Columbia Generating Station study began in 1971 when three Wisconsin utilities (Wisconsin Power and Light Company, Madison Gas and Electric Company, and Wisconsin Public Service Corporation) asked the University of Wisconsin-Madison to study the impact of construction and operation of a new coal-fired generating station at Portage, Wisconsin. It was hoped that the study would result in newer, less expensive methods for measuring environmental change.

The three utilities funded the study at $45,000/yr from January 1971 to 25 June 1975. In July 1975, the Environmental Protection Agency became the funding agency and increased funding approximately ten-fold for the period July 1975 through July 1978. The study was expanded and reorganized. In addition to monitoring and documenting the effects of the generating station on the environment, the investigators now attempted to understand the interactions among these changes so that power plant impacts could be predicted and perhaps manipulated in the future. The entire study was divided into two major components--one to study terrestrial systems and one to study aquatic systems. The remote sensing group was made part of the aquatic systems division.

The Columbia Generating Station is in west central Columbia County, along the Wisconsin River floodplain, 4 miles (6.4 km) south of Portage, Wisconsin. The site covers 1,100 ha (Figure 1) and includes the generating units and coal storage area (110 ha), the cooling lake (200 ha) and the ashpit (30 ha).

Before plant construction the site consisted of extensive marsh/sedge meadow, floodplain forest, and a few low semi-wooded knolls (Figure 2). The marsh/sedge meadow community floods to varying depths during the spring and occasionally during the fall. The study site is wettest in the spring and becomes progressively drier through summer. Although the area was comprised primarily of sedges and grasses, it included small areas of open water with emergent vegetation as well as pockets of shrub carr and alder thicket.

The marsh/sedge meadow soil is a peat mat 3 to 4 feet thick overlying sand. The meadow is bounded on the north by Duck Creek and on the south by Rocky Run Creek. Before plant construction there was no apparent surface flow between these streams across the sedge meadow. However, ground water moved through the meadow toward the river from a large area to the southeast (Figure 3).

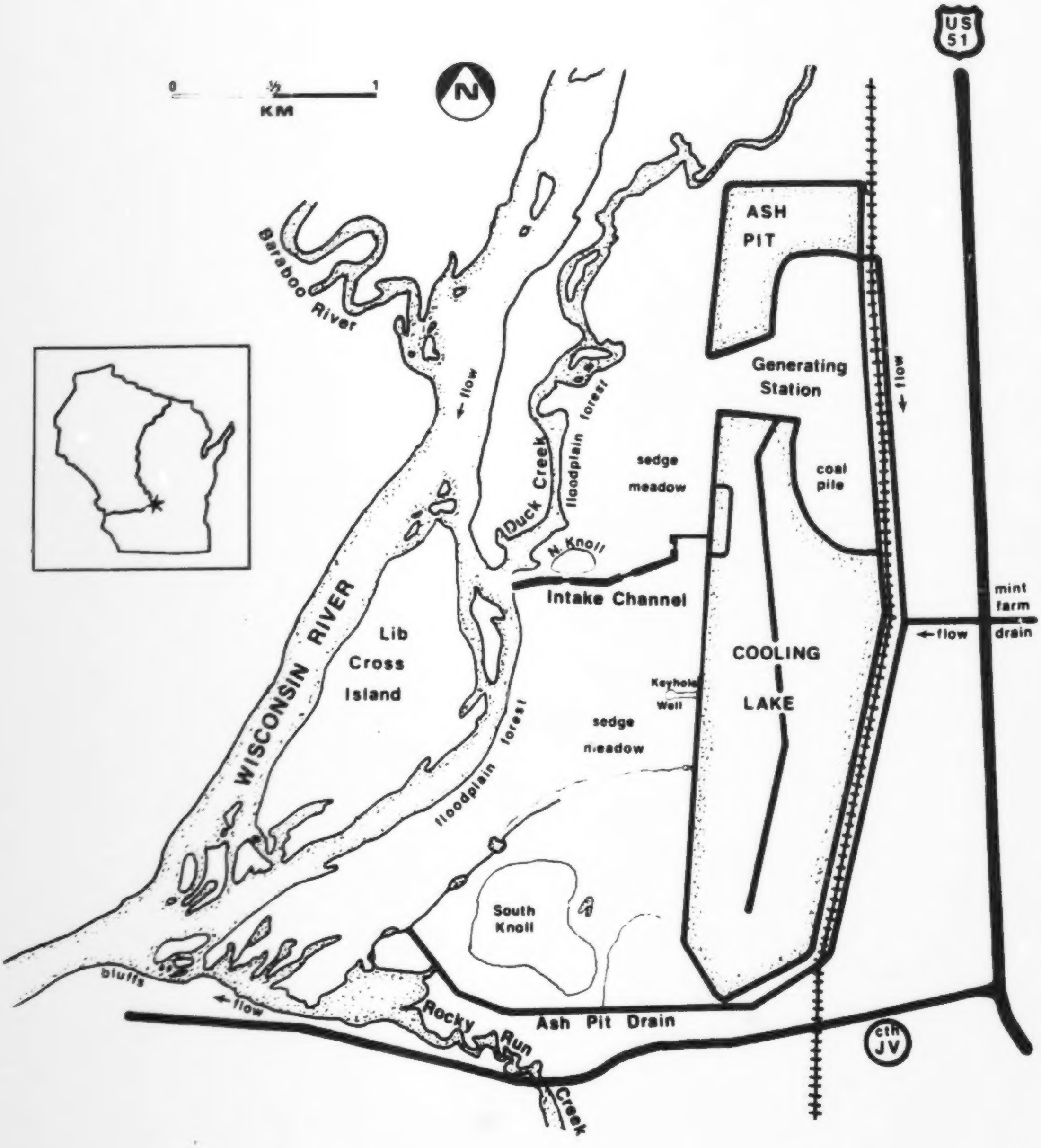

0
½
1
KM
N
US 51
Baraboo River
flow
Duck Creek
floodplain forest
ASH PIT
Generating Station
flow
sedge meadow
coal pile
N. Knoll
Intake Channel
mint farm drain
flow
WISCONSIN RIVER
Lib Cross Island
COOLING LAKE
Keyhole Well
sedge meadow
floodplain forest
South Knoll
bluffs
flow
Rocky Run Creek
Ash Pit Drain
cth JV

Figure 1. Columbia Generating Station site showing location of ashpit, generation station, coal pile, cooling lake, and marsh/sedge meadow.

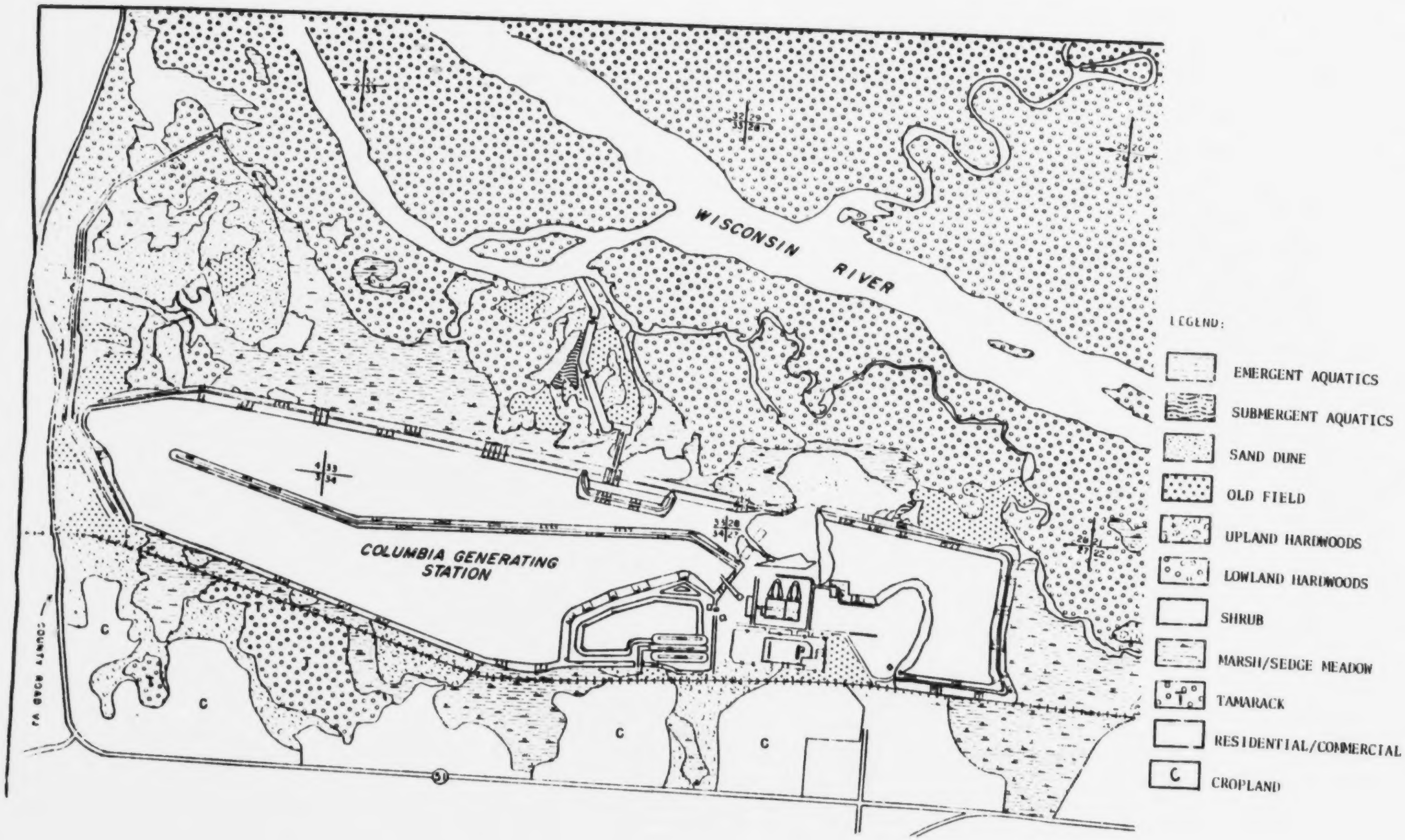
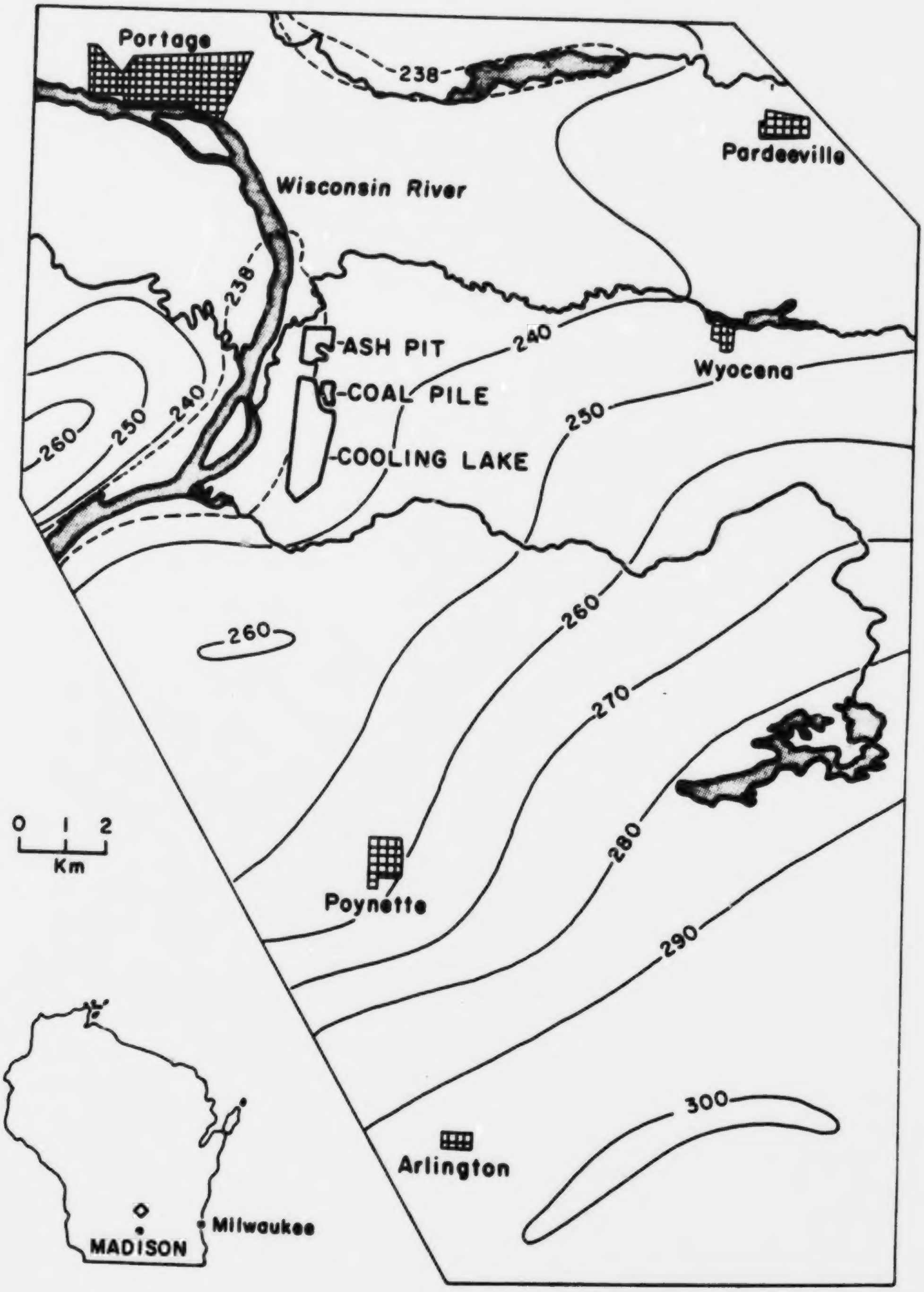

WISCONSIN RIVER
COLUMBIA GENERATING STATION
COUNTY ROAD VJ
51
C
LEGEND:
EMERGENT AQUATICS
SUBMERGENT AQUATICS
SAND DUNE
OLD FIELD
UPLAND HARDWOODS
LOWLAND HARDWOODS
SHRUB
MARSH/SEDGE MEADOW
TAMARACK
RESIDENTIAL/COMMERCIAL
CROPLAND

Figure 2. Dames and Moore vegetation map of site drawn in 1972.



Portage
238
Pardeeville
Wisconsin River
238
ASH PIT
240
COAL PILE
Wyocena
260
250
240
250
COOLING LAKE
260
260
270
0 1 2
Km
280
Poynette
290
300
Arlington
Milwaukee
MADISON

Figure 3. Groundwater contours of the area (from Andrews, 1977).

## IMPACTS OF PLANT CONSTRUCTION AND OPERATION ON THE STUDY SITE

Major impact commenced in 1971 when much of the site was cleared and construction on the cooling lake was started.

The power plant generating units and coal storage area were built on high ground previously occupied by a mix of dry oak forest, prairie, and old field vegetation. However, the cooling pond and a portion of the ashpit were built directly over the sedge meadow. This required construction of an earthfill dike (April 1971) to contain the pond and a drainage ditch on the southeast side of the marsh (September 1973) to divert natural ground and surface flow around the cooling lake. Figure 4 shows ground-water movement through the study site before and after construction of the cooling lake and drainage ditch. Construction on the ashpit also was begun in 1973 (Figure 5).

An attempt was made to fill the cooling lake in June 1974 but it leaked badly. Therefore it was drained and a clay sealer, bentonite, was sprayed on the bottom and sides. The pond was refilled in January 1975 and two months later Unit I went on line.

Most severe ground-water temperature dislocations occur within 100 m of the dike (Figure 6). On 28 October 1976 ground-water temperatures at a depth of 1.5 m beneath the surface ranged from greater than 23°C to less than 10°C. Six months later, on 26 April 1977 (before Unit II went on line) temperatures at a depth of 1.5 m ranged from 13°C to 5°C, showing that the ground water near the dike was becoming cooler rather than warmer at this time of the year. By 25 July 1977 ground-water temperatures again ranged from 10°C to more than 23°C. With two units in operation, the area of ground water elevated to 20°C is larger than with only one unit in operation.

After construction of the cooling lake, the marsh/sedge meadow vegetation responded dramatically to three impacts--elimination of seasonal water level fluctuations (Figure 7), increase of ground-water flow, and year-round thermal loading of the ground water. The increased ground-water flow is rapidly eroding the peat mat. In addition, thermal loading is causing some vegetation to die so that its anchoring roots no longer produce new peat mat. This augments the erosiveness of the ground water. Large channels of open water are now visible through the marsh/sedge meadow where originally there were none.

Plant species have reacted in various ways. According to Bedford (1977), the major responses are: 1) Species dying out due to increased water level; 2) species increasing due to increased water level; 3) species dying out due to out-of-synch water temperatures; 4) species increasing due to increased water temperatures; 5) species dying out due to mechanical water action which removes protective litter, particularly important for the

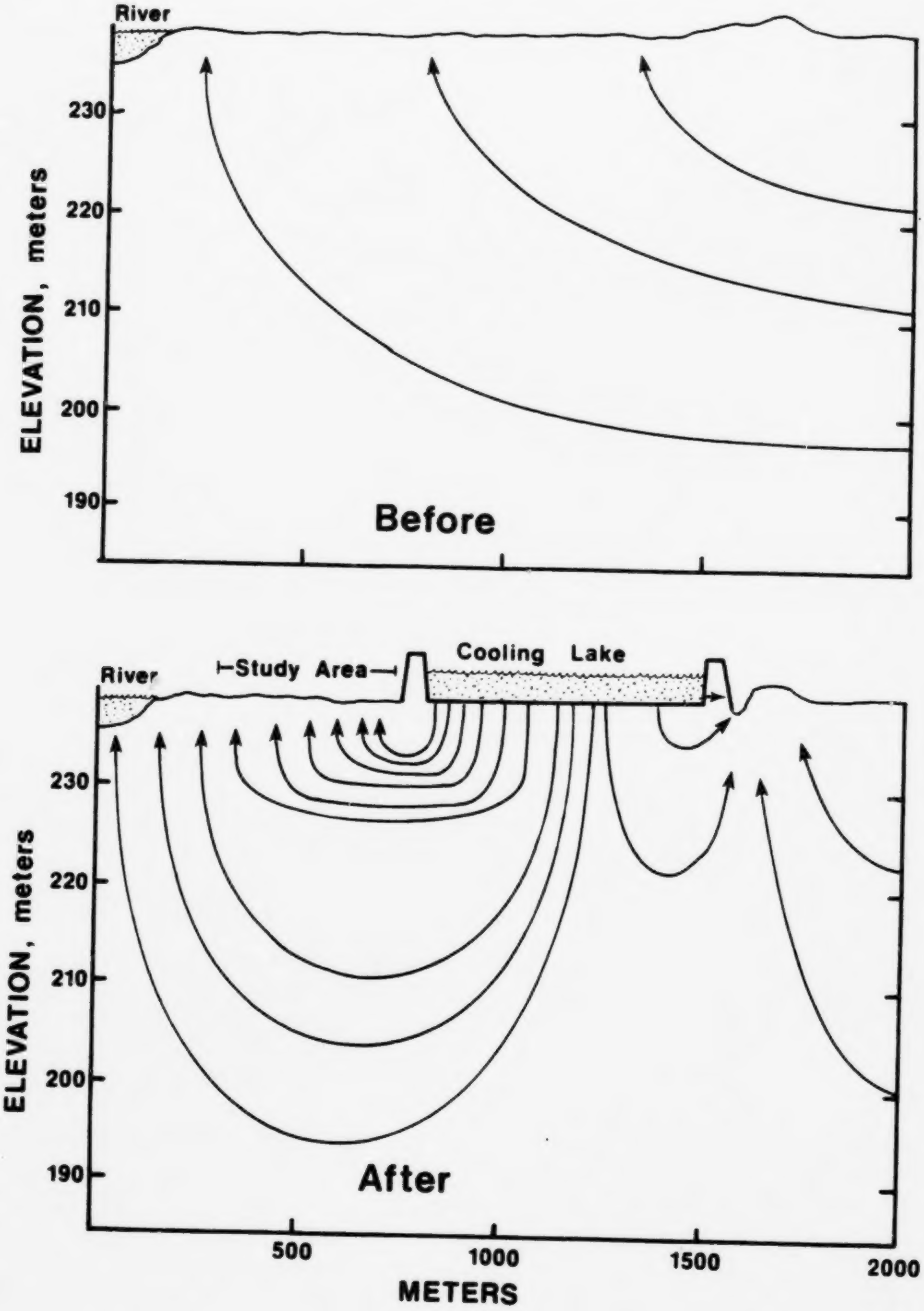

River
230
220
210
200
190
ELEVATION, meters
Before
River
Study Area
Cooling Lake
230
220
210
200
190
ELEVATION, meters
After
500
1000
1500
2000
METERS

Figure 4. Groundwater movement through the site before and after construction of cooling lake (from Andrews, 1977).

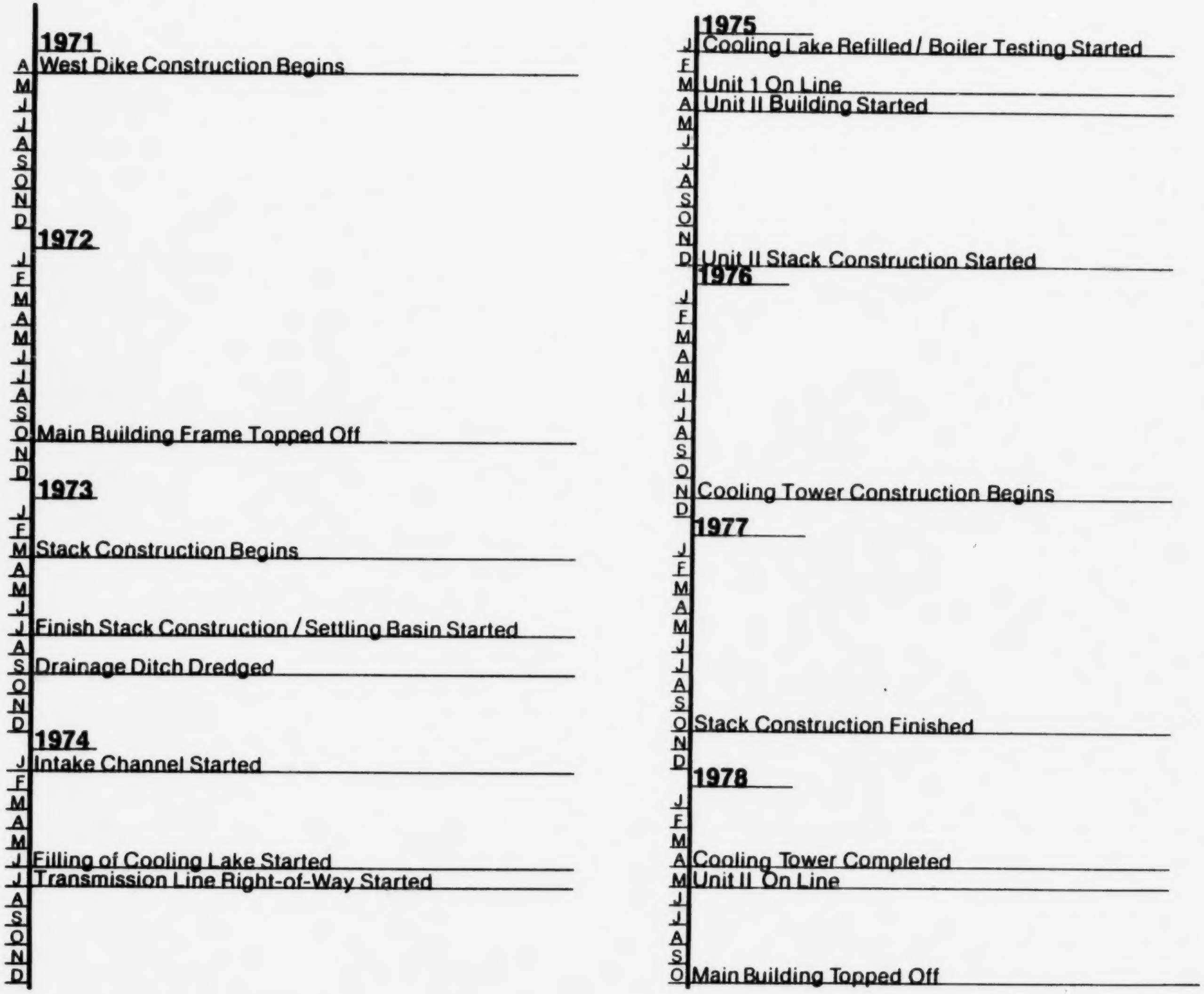


Figure 5. Time line of construction events at the Columbia Generating Station.

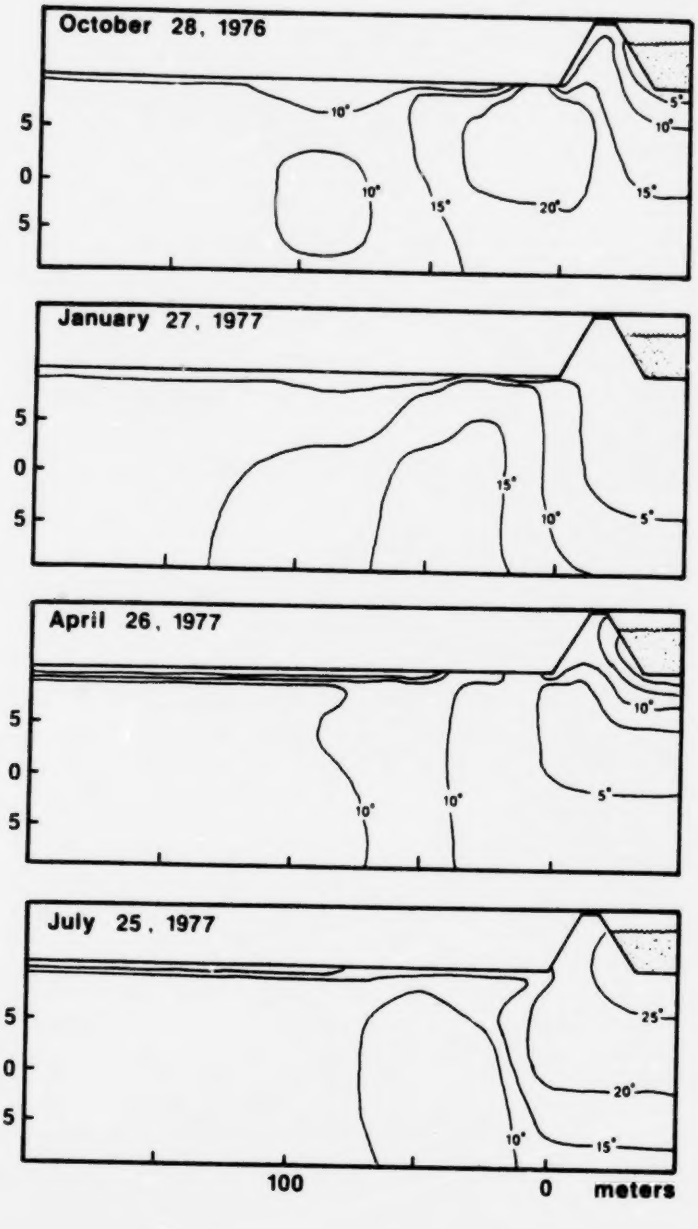


Figure 6. Groundwater isotherms at various depths and distances from the cooling lake dike in October 1976 and January, April and July 1977. Note the depth and distance of the isotherms showing warmest temperatures (from Andrews, 1977).

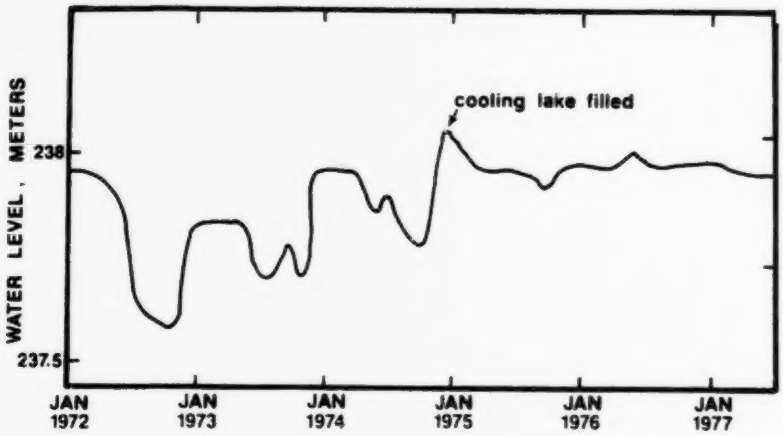


Figure 7. Wetland water level fluctuations (from Andrews, 1977).

over wintering of the next year's growth; and 6) weedy annual species increasing in areas where peat and mud are exposed.

Vegetation responses to the cooling lake impacts were analyzed from several different perspectives: Changes in community growth form and associated bird life (Jaeger 1979); physiological causes of species' declines or increases (Bedford 1977); and changes in species and community occurrences with time.

The latter approach is the subject of this report. The study attempts to 1) document community and species change from the ground and from the air and 2) compare the efficiency, sensitivity and reliability of various monitoring methods for detecting vegetation change.

Much of the literature describing environmental monitoring and impact assessment techniques is directed at the needs of those preparing environmental impact statements. Many theoretical papers discuss what the environmental impact statement process should include (Bisset 1978, Sondheim 1978). Some address components that might be considered in a statement (Leopold et al. 1971, Fischer and Davies 1973) and various ways of treating them (Warner and Bromley 1974, McHarg 1969). A few state specifically what data might be collected for terrestrial or aquatic studies (Johnson 1974). Fewer still either suggest or evaluate data collection methods (Eberhardt 1976).

Traditionally, vegetation monitoring studies have been conducted on the ground (Hough 1965, Bunce and Shaw 1973, Muller-Dombois and Ellenberg 1974, and Smith et al. 1975). Now, however, remote sensing methods are used to map vegetation (Cowardin and Myers 1971, Johnson 1974, Brown 1978, and Gammon and Carter 1979), locate manmade linear features (roads, pipelines), and evaluate terrain sensitivity (Dirschl and Dabbs 1972). While many remote sensing papers emphasize the need for adequate ground verification, few describe how verification should be accomplished (Enslin and Sullivan 1974). The techniques discussed here are a step in this direction.

Incorporating several classification methods to analyze ground sampling and remote sensing data, this study demonstrates vegetation changes with time. The methods chosen represent a variety of traditional and new methods; together they provide many levels of information. Selection of the various methods was based on their appropriateness for analyzing and documenting vegetation changes specific to the Portage setting, where a coal-fired power plant was constructed and operated in a marsh/sedge meadow.

This study attempts 1) to document species and community change from the ground and from the air and 2) to compare the efficiency, sensitivity and reliability of the selected monitoring methods in detecting vegetation change. Recommendations are made for effectively combining ground sampling and airphoto data collection and analysis methods. These ground sampling and airphoto methods were specifically selected to monitor change for an Environmental Protection Agency study; they might also find use in environmental impact statements, resource surveys, land-information systems, and litigation (Anderson and Wobber 1973, Fornes and Reimold 1973, Frazier and Lee 1975, and Lillesand and Kiefer 1979).

Extensive ground sampling data were collected in the Portage wetland from 1974-77. These data were analyzed to create: 1) A diversity index, 2) a subjective classification, 3) an association analysis classification, and 4) a vegetation structure classification.

Numerous color and color infrared airphotos of the wetland were taken over the same period of time. These photos were used as a data base to record community change. Generalized disturbance maps were drafted from them. Airphoto and ground samplng data were used together to generate: 1) relative percent cover changes, 2) airphoto interpreted vegetation maps, and 3) computer-assisted vegetation maps.

Specifically, the questions under examination in this report are:

1) Using these techniques, can species changes be detected with time?
2) Which techniques detect species changes most efficiently?
3) Using these techniques, can community area and location changes be detected with time?
4) Which techniques detect community changes most efficiently?
5) Can trends in vegetation changes be documented with these techniques?
6) Which techniques do so most efficiently?

# SECTION 2

# CONCLUSIONS

This study was part of a large U.S. Environmental Protection Agency study designed to monitor the impacts of the construction and operation of a coal-fired power plant located near Portage, Wisconsin. The study demonstrated and evaluated nine methods used to document the deterioration of a large wetland located at the power plant site over a 3-yr period. Four of the nine methods (diversity index, subjective classification, association analysis, and structure analysis) used ground sampling data. Two methods, airphoto monitoring and disturbance mapping, used airphoto data only, while airphoto grid analysis and airphoto interpreted vegetation mapping used airphoto and ground sampling data. The ninth method, computer-assisted mapping, used only airphoto data but relied heavily on the analyst's on-the-ground knowledge of the area.

These methods were evaluated on a basis of whether they monitor vegetational change at a species or community level, whether or not they monitor community change in terms of area and/or location, and whether or not they provide information about community trends. These methods were also evaluated on the basis of time, cost, sensitivity and reliability.

Of the nine methods, only the diversity index, a ground sampling data method, documented species change with time. The other three ground sampling data classification methods dealt with community change and documented that change by analysis of species appearance and disappearance.

All methods--other than the diversity index--documented changes in vegetation community area, vegetation community location, or both. The ground sampling methods showed point locations of communities which were mapped. They also quantified changes in relative percent of sampling points classified as a particular class. Subjective classification is the most sensitive and the most expensive of the three ground sampling methods; vegetation structure analysis is least sensitive and least expensive while the association analysis handles large quantities of data better than either of the other two classification methods.

Airphoto methods can better document community area and location changes than can ground sampling data methods. Airphoto monitoring, a purely descriptive method, is the least effective of the airphoto methods, offering only a series of airphotos as a record of change. It does offer the advantage of not requiring any ground verification, a feature which it shares with the disturbance mapping method. Disturbance mapping, a low cost method, uses a series of maps to record change. Its greatest disadvantage is that it delineates only three classes--disturbed and undisturbed vegetation and open water. In defining only three classes, however, this method creates an exceptionally understandable visual record of change taking place.

Airphoto grid analysis, the second most costly method, records percent cover of vegetaton classes on a cell basis. This method documents percent changes in community area but does not directly document changes in community location.

Airphoto interpreted vegetation mapping, the most costly method, was used to map the greatest number of vegetation classes of all the methods. A series of photo-interpreted vegetation maps documents changes in community location and area. Relative percent cover changes can be quantified using either a planimeter or overlaying maps with a grid and counting cells of each vegetation type.

Computer-assisted mapping, the third most expensive method, generates computer-quantified vegetation maps. If vegetation classes can be correctly defined and identified during training set selection, this is the most reliable (consistent) of the quantitative cover estimation methods. This method also demonstrates changes in community location. The color film products which can be made using this method provide the best visual documentation of change of any of the nine methods. If the vegetation classes being mapped are reliably identified, the film products and quantified area cover information this method generates, definitely warrant its high cost.

In this particular study where the user of the information collected and analyzed is the U.S. Environmental Protection Agency, the following combination of methods are probably the most efficient, sensitive and reliable to study wetland vegetation change.

Association analysis (using presence-absence data) should be used to analyze data collected over time to demonstrate the manner in which vegetation communities are changing, year by year. If the equipment and package of programs necessary to use computer-assisted mapping are available, the analyst recommends using this method to quantify change in community area and to demonstrate change in community location. If computer-assisted mapping cannot be used, the analyst recommends using airphoto-interpreted vegetation mapping to supply community location and area information.

## SECTION 3

## RECOMMENDATIONS

This study had several shortcomings. Perhaps the greatest is that there is no "truth" against which to compare the results of the methods being tested. No detailed vegetation map exists of the site prior to the start of construction.

Another shortcoming was the attempt to do ground sampling over too large an area which led to inconsistent ground sampling, from one year to the next. Sampling should not have been done over such an extensive area because the greatest amount of sampling time and effort went into hiking between sampling stations instead of into the actual sampling.

Another shortcoming was the failure to place permanent surveyed airphoto targets at selected sampling stations so there would be two or three targets identifying each vegetation community. This was not done due to a reluctance to install permanent markers which would kill the vegetation. In view of the destruction which has taken place at the study site, target damage to the site would have been inconsequential. Perhaps a more valid reason for not placing targets was that the difficult terrain made placing any kind of markers a monumental task. Targets are needed on airphotos to use in vegetation class identification, particularly when using computer-assisted mapping. Selecting training sets from target areas of known vegetation is one way to assure the method's accuracy.

In approaching a similar situation in the future, documenting impact at a study site without knowing where it would happen or the form it would take, the procedure described in the next two paragraphs would most likely provide the best results.

Permanent markers (targets) would be located at a selection of the sampling stakes so that each community was targeted at least twice and preferably three times. The location of these targets would be based on surveying. Target size would be such that it could be identified on the smallest scale airphotos used.

Data analysis could depend on use. The ground data would be classified using either subjective classification or association analysis in order to record and understand the changes exhibited by the vegetation. And the various vegetation communities could be mapped to visually demonstrate changes in area and location with time. The first choice of method to use for this would be computer-assisted mapping if sufficient funds were available. With targeted communities, accurate classification would be assured. Otherwise, airphoto interpreted vegetation mapping would be recommended.

# SECTION 4

# MATERIALS AND METHODS

Extensive ground sampling and airphoto data were collected between 1974 and 1977 in the study area (the 33.5 ha of marsh/sedge meadow west of the cooling lake's west dike (Figure 8)). The data collection techniques that were chosen represent a range of scales, costs and detail.

## GROUND SAMPLING DATA COLLECTION

Ground sampling data were collected from 1974 to 1977 by members of the Remote Sensing Group and the Wetlands Ecology Group. The 33.5 ha study site was marked off into east-west transects spaced at 50 m intervals. Sampling stations were established at 50 m intervals along these transects, forming a grid. At each sampling station two circular 0.25 $m^2$ quadrats were laid out. Species and/or numbers of stems/species were recorded for each quadrat. The size of the circular quadrats (0.25 $m^2$) was selected because the grasslike growth form of sedge and grass species made use of a larger quadrat impractical. Wetland vegetation of this type is susceptible to trampling. To minimize the effects of trampling, two quadrats were laid out randomly within the four quadrants at each station.

Water temperature (°C) was measured at the surface and in the vegetation rooting zone; water depth (cm) was measured at the level of solid substrate below the rooting zone. Air temperature (°C) also was measured at each sampling station. Water quality was assessed subjectively, by visual estimate. The presence or absence of a floating mat was noted at each sampling station as well as direction of water flow. Volume of water flow was subjectively classified as absent, gentle, moderate or swift. Soil substrate was classified according to six types; muck, open water, consolidated peat, unconsolidated peat, sand or upland.

Table 1 provides an example of encoded data collected during fall 1976. The first four columns identify the year and month in which the data were recorded. Columns five to nine identify transect, stake, and quadrat numbers. Columns 10 to 26 record environmental parameter data (data used by the Wetlands Ecology Group). Column 31 begins a series of six column units: the first three columns identify the species, while the last three record the number of stems counted for that particular species. The species codes are listed in Appendix A.

Figure 8. Color infrared airphoto of study site on July 24, 1976.

### TABLE 1. EXAMPLE OF ENCODED GROUND SAMPLING DATA AND SCHEME WITH WHICH THEY WERE CODED

```
77   430061 15    141634      4    016075028002
77   430064 14    142266      4    030007008008
77   430074 12    1209371     4    016075030013
77   430072 12    1213581     4    016075030013
77   430082 12    12  17    174    008017016050
77   430084 12    121826    174    008001016050
77   430091 10    1010521     4    016050131004030002
77   430094 10    101452      4    016050030014
77   430104110    101649      4    016025030005
```

| Column number | Information |
|---|---|
| 1-2 | Year |
| 3-4 | Month |
| 5-6 | Transect |
| 7-8 | Stake |
| 9 | Quadrat |
| 10 | Water quality |
| 11-12 | Water temperature at surface |
| 13-14 | Water temperature at base of plant |
| 15-16 | Water temperature in rooting zone |
| 17-18 | Water depth to solid substrate |
| 19-20 | Water depth to rooting zone |
| 21 | Floating mat; 1=present, 2=absent |
| 22 | Direction of water flow; 0=absent, 1=N, 2=NE, 3=E, 4=SE, 5=S, 6=SW, 7=W, 8=NW |
| 23 | Volume of water flow; 0=absent, 1=gentle, 2=moderate, 3=swift |
| 24-25 | Air temperature |
| 26 | Soil substrate code; 1=muck, 2=open water, 3=consolidated peat, 4=unconsolidated peat, 5=sand, 6=upland |
| 31+ | Three letter species code followed by three letter species count |

Sampling took place each summer and fall from 1974 to 1977. However, the number of stations sampled varied throughout the study. During summer and fall 1974 species stem counts data were collected at every other station at 100 m intervals. In 1975, species presence-absence data and stem counts data were collected at every other station at 100 m intervals. In 1975, species presence-absence data and stem count data were collected at alternating stations. In the fall seasons of 1976 and 1977, judging stem counts data more valuable than presence-absence data, the Remote Sensing and Wetland Ecology Groups collected stem counts data at every station. In the summers of 1976 and 1977 only a select number of stations were sampled by the Wetlands Ecology Group. These variations in the sampling scheme reduced the data actually used for analysis in this study. Analysis was limited to records obtained from stations that were sampled in each of the fall dates 1974 to 1977. These 62 stations are located between transects 18 and 40 and are listed in Appendix B.

## AIRPHOTO DATA COLLECTION

Airphoto data were collected at more frequent intervals than the ground sampling data. Airphotos were taken once a month during the growing season and several times over the winter months. In the spring and fall of 1976, airphotos were taken every few days in order to document the rate at which the vegetation sprouted and later died back, as recorded on the airphotos.

In 1973 and 1974, Nikon cameras were used to take 35 mm color and color infrared photos of the study site at several scales. Beginning in March 1973, two Hasselblad cameras were used to take 70 mm color and color infrared airphotos using Kodak 2443 and 2448 film. Photos were usually taken at scales of 1:38,200 (5,000 ft above mean terrain) and 1:19,100 (2,500 ft above mean terrain). Occasionally, photos were taken at scales of 1:76,400 (10,000 ft above mean terrain) and 1:19,100 (2,500 ft above mean terrain). Occasionally, photos were taken at scales of 1:76,400 (10,000 ft above mean terrain) and 1:11,500 (1,500 ft above mean terrain). Several scales were tested to determine which was best suited to computer-assisted mapping. Table 2 lists the imagery obtained for this study.

## MONITORING VEGETATION USING GROUND SAMPLING DATA

Ground sampling data were analyzed to generate 1) a diversity index, 2) a subjective classification, 3) association analyses, and 4) a vegetation structure classification. These techniques represent a range of detail and costs; they are described separately below.

### TABLE 2. COLUMBIA GENERATING STATION AIRPHOTOS, 1949 to 1977

| Date | Film type | Scale | Source | Transparency format |
|---|---|---|---|---|
| 27 May 1949 | Black & White | 1:20,000 | ASCS[a] | 9"x9" |
| 7 Jan. 1967 | Black & White | 1:15,480 | DOT[b] | 9"x9" |
| 13 May 1968 | Black & White | 1:20,000 | ASCS | 9"x9" |
| 4 April 1970 | Black & White | 1:6,000 | ALSTER[c] | 9"x15" |
| 24 May 1971 through 17 Aug. 1972 | Black & White Obliques | | Airpix[d] | 9"x9" |
| Autumn, 1971 | Color Infrared | | LL[e] | |
| 4 April 1971 | Black & White | 1:7,900 | DNR[e] | |
| 14 April 1971 | Black & White | 1:6,600 | DNR | |
| 13 May 1971 | Black & White | 1:7,900 | DNR | |
| 4 Aug. 1971 | Black & White | 1:1,200 | DOT | |
| 10 April 1972 | Color<br>Infrared | 1:120,000<br>1:24,000 | UW[g] | 35 mm |
| 11 April 1972 | Color<br>Infrared | 1:12,000<br>1:24,000 | UW | 35 mm |
| 13 May 1972 | Black & White | 1:7,900 | DNR | 9"x9" |
| 4 June 1972 | Color & Color IR | 1:120,000 | NASA[h] | 9"x9" |
| 27 Sept. 1972 | Black & White IR | 1:7,900 | DNR | 9"x9" |
| 13 Nov. 1972 | Color IR | | UW | 35 mm |
| 18 March 1973 | Color | | DNR | 9"x9" |
| 14 June 1973 | Color & Color IR | 1:32,300 | UW | 35 mm |
| 12 Oct. 1973 | Color & Color IR | 1:30,500<br>1:29,200<br>1:60,900 | UW | |
| 8 Nov. 1973 | Color & Color IR | 1:60,900 | UW | 35 mm |
| 15 April 1974 | Color & Color IR | 1:12,200<br>1:24,400 | UW | 35 mm |
| 16 April 1974 | Color & Color IR | 1:17,000 | UW | 35 mm |
| 24 May 1974 | Color | 1:17,000 | UW | 35 mm |
| 4 June 1974 | Color | 1:12,200 | UW | 35 mm |
| 17 June 1974 | Color IR | 1:12,200 | UW | 35 mm |
| 31 July 1974 | Color & Color IR | 1:120,000 | NASA | 35 mm |
| 7 Aug. 1974 | Color IR | 1:24,400<br>1:54,800 | UW | 35 mm |
| 8 Aug. 1974 | Color IR | 1:24,400 | UW | 35 mm |
| 8 Aug. 1974 | Color | 1:54,800 | UW | 35 mm |
| 10 Oct. 1974 | Color IR | 1:18,300<br>1:22,200 | UW | 35 mm |
| 10 Oct. 1974 | Color | 1:24,400 | UW | 35 mm |
| 22 Nov. 1974 | Black & White | 1:24,000 | DOT | 9"x9" |
| 19 March 1975 | Color & Color IR | 1:19,100<br>1:38,200 | DNR | 70 mm |
| 19 March 1975 | Color | 1:76,400 | DNR | 9"x9" |

(continued)

TABLE 2 (continued)

| Date | Film type | Scale | Source | Transparency format |
|---|---|---|---|---|
| 19 March 1975 | Color | 1:76,400 | DNR | 9"x9" |
| 13 June 1975 | Color | | DNR | 9"x9" |
| 10 July 1975 | Color & Color IR | 1:38,200 | DNR | 70 mm |
| 16 July 1975 | Color & Color IR | 1:76,400 | UW | 70 mm |
| 17 Aug. 1975 | Color & Color IR | 1:76,400 | UW | 70 mm |
| 26 Aug. 1975 | Color & Color IR | 1:76,400 | UW | 70 mm |
| 25 Sept. 1975 | Color & Color IR | 1:76,400<br>1:38,200 | UW | 70 mm |
| 6 Oct. 1975 | Color & Color IR | 1:76,400 | UW | 70 mm |
| 5 Nov. 1975 | Color & Color IR | 1:38,200<br>1:76,400 | UW | 70 mm |
| 7 Jan. 1976 | Color & Color IR | 1:19,100<br>1:38,200<br>1:11,500 | UW | 70 mm |
| 1 March 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 11 March 1976 | Color | Obliques | UW | 35 mm |
| 20 March 1976 | Color | Obliques | UW | 35 mm |
| 1 April 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 8 April 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 19 April 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 4 May 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 11 May 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 21 May 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 5 June 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 17 June 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |

(continued)

TABLE 2 (continued)

| Date | Film type | Scale | Source | Transparency format |
|---|---|---|---|---|
| 24 July 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500<br>1:5,700 | UW | 70 mm |
| 3 Sept. 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 24 Sept. 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500<br>1:5,700 | UW | 70 mm |
| 26 Oct. 1976 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 7 Feb. 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 1 March 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 26 April 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 25 June 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 11 July 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 15 Aug. 1977 | Color & Color IR | 1:38,200<br>1:19,100<br>1:11,500 | UW | 70 mm |
| 3 Oct. 1977 | Color & Color IR | 1:11,500 | UW | 70 mm |

---

[a] Agricultural Stabilization and Conservation Service (USDA).

[b] Department of Transportation, State of Wisconsin.

[c] Alster & Associates, Madison, Wisconsin.

[d] AIRPIX, 2610 North Laramie, Chicago, Illinois.

[e] Landscapes Limited, Madison, Wisconsin (No longer in operation).

[f] Department of Natural Resources, State of Wisconsin.

[g] University of Wisconsin, Institute for Environmental Studies, Environmental Monitoring and Data Acquisition Group, Madison, Wisconsin.

[h] National Aeronautics and Space Administration.

## Diversity Index

The diversity index (Table 3) gives information about yearly changes in the numbers of species based upon field data collected over several years. The total number of species found at all 62 sampling stations was summed for each year of the study (see Appendix C). In 1975, for example, the total number of species found at all 62 stations was 379. By 1977, the total had dropped to 266, a loss of 30%.

TABLE 3. DIVERSITY INDEX, 1974-77

| Year | Numbers of species | Species loss/yr (%) |
|---|---|---|
| 1974 | 379 | |
| 1975 | 357 | 5.8 |
| 1976 | 296 | 17 |
| 1977 | 266 | 10 |

Species losses reflect the impacts taking place each year. In 1974 and 1975 the cooling lake was filled and peat mat erosion had begun due to the increased ground-water flow. Species loss reached 22 species or 5.8% by the time Unit I went on line in March 1975. At that time water moving from the cooling lake into the marsh/sedge meadow began carrying a thermal load which speeded up wetland destruction. This is reflected in the 61 species (17%) lost that year. By 1976 and 1977 many of the species most sensitive to disturbance had already disappeared. Species loss for that year dropped back to 30 species or 10% of the original total.

The diversity index also provided a means to record the total number of occurrences of weedy species appearing each year. Species defined as weedy were the annuals *Bidens cernua, Pilea pumila,* and *Lemna minor*. If a sampling quadrat was empty of all vegetation, indicating it was very badly disturbed, a value of three was recorded for it. Each weedy species was assigned a value of one. When totals were obtained by this method, weedy species were shown to increase from 17 in 1974 to 69 in 1977, a 405% increase.

## Subjective Classification

In order to demonstrate community change station by station, the data collected at each of the 62 sampling stations were assigned a vegetation classification according to species present, 1974-77. Most of the vegetation classes used were defined subjectively by Bedford (1977).

1) *Carex stricta* prominent; mixed with other sedges, grasses, forbs and ferns. *Carex lacustris, Calamagrostis canadensis Spartina pectinata,* and *Sagittaria lutifolia* locally abundant.

2) *Carex lacustris* prominent, with *Carex stricta, Calamagrostis canadensis,* and *Sagittaria latifolia* locally abundant.

3) Mixed *Transition* zone between sedge meadow and emergent aquatics; *Calamagrostis canadensis, Sagittaria latifolia, Carex rostrata, Carex lacustris* locally abundant.

4) Locally prominent emergent aquatics: *Typha latifolia, Carex lacustris, Sparganium eurycarpum, Scirpus fluviatilis, Acorus calamus, Sagittaria latifolia, Carex rostrata.*

5) *Spiraea alba* prominent in the shrub overstory; understory similar to *Carex stricta* areas.

6) Shrubs (*Salix* spp. and *Cornus stolonifera*) and lowland trees (*Populus tremuloides, Ulmus americana, Salix nigra, Acer saccharinum*).

In order for a sampling station to be classified as one of these six classes, those species listed as prominent had to make up 60% of the stems in the quadrat.

Since the study area changed in composition quite rapidly, several classes had to be added. The first stage of change at the study site required the addition of four Degraded classes:

7) Degraded *Carex stricta*

8) Degraded *Carex lacustris*

9) Degraded Transition

10) Degraded Emergents

Stations placed in any of these Degraded classes had enough of the prominent species to identify them as a particular community but lacked accompanying species and adequate numbers of all species. All stations classified as degraded had high *Lemna minor* (duckweed) counts indicating open, still water and little shading vegetation.

Further damage, resulting in complete erosion of the peat mat, required the addition of two more classes:

11) Weedy annuals prominent; areas of floating peat exposed to the air and often covered with *Bidens cernus* and/or *Pilea pumila* seedings

12) Open water areas where both the vegetation and peat mat had been so thoroughly destroyed that only open water remained.

The subjective classification demonstrated changes with time in terms of the changing numbers of stations assigned to each vegetation class (see Appendix D). This method also made it possible to correlate vegetational changes with changes in water temperature, volume of water flow, and peat mat erosion.

Table 4 lists the number and percent of the total number of sampling stations subjectively assigned to each vegetation class over a 3-yr period. In 1974, 47% of the sampling stations were classified as sedges (*Carex stricta* and *Carex lacustris* classes). By 1976 this number had decreased to 26% and dropped to 16% in 1977. The *Carex lacustris* community almost disappeared entirely between the summers of 1974 and 1976. *Carex lacustris* is a clone forming species. When the cooling lake was filled (1974 and 1975), upwelling and greatly increased surface flow in the marsh/sedge meadow resulted in exposure and mechanical damage to the next year's shoots of *Carex lacustris*. Flowing water carried away detritus, which normally acts as a protective mulch for young sedge shoots, causing peat mat erosion. The *Carex stricta* community survived better initially because its tussock growth form kept the next year's shoots above water during the winter. However, *Carex stricta* is being destroyed more slowly by erosion eating away the peat mat where the individual tussocks are anchored.

In 1974, 19% of the sampling stations were classified as Transition. By 1976 and 1977, only 6% of these stations could be classified Transition. The Emergents community decreased only slightly in numbers from 17% in 1974 to 13% in 1977. The Emergents class, which grows in deeper water, has been able to spread into new habitat with the deeper water condition and has therefore shown smaller losses than the Transition class.

Stations classified Degraded, Weedy Annual or Open Water increased from 1.5% in 1974 to 11% in 1975 and to 37% in 1977. This again indicates that the greatest damage took place in 1975 and 1976; the first year of thermal loading. Sampling stations classified Open Water increased from none in 1974 to 14% in 1977. Stations classified as *Spiraea* or Shrubs remained constant between 1974 and 1977, reflecting their slower response to changing conditions.

Table 5, which summarizes the reclassification of the sampling stations using subjective classification, demonstrates the fragility of each community. Over half of the stations originally classified as *Carex lacustris*, Transition, and Emergents evolved in 3 yrs to Degraded, Weedy Annuals or Open Water classifications. The *Carex lacustris* community appears the most fragile since only one station out of an initial 15 (6,7%) retained that classification. In the Transition community, one station out

TABLE 4. SUMMARY OF SUBJECTIVE CLASSIFICATION

| Vegetation class | 1974 | | 1975 | | 1976 | | 1977 | |
|---|---|---|---|---|---|---|---|---|
| | No. of stations | Relative % | No. of stations | Relative % | No. of stations | Relative % | No. of stations | Relative % |
| *Carex stricta* | 15 | 24 | 16 | 26 | 14 | 23 | 9 | 14.5 |
| Degraded *Carex stricta* | | | 1 | 1.6 | 4 | 6.5 | 10 | 16.1 |
| *Carex lacustris* | 14 | 23 | 9 | 14 | 2 | 3.2 | 1 | 1.6 |
| Degraded *Carex lacustris* | | | 1 | 1.6 | 6 | 9.7 | 3 | 4.8 |
| Transition | 12 | 19 | 9 | 14 | 4 | 6.5 | 2 | 3.2 |
| Degraded Transition | | | 2 | 3.2 | 4 | 6.5 | 4 | 6.5 |
| Emergents | 11 | 17 | 12 | 19 | 11 | 18 | 8 | 12.9 |
| Degraded Emergents | | | 1 | 1.6 | 3 | 4.8 | 6 | 9.6 |
| *Spiraea* | 3 | 4.8 | 3 | 4.8 | 3 | 4.8 | 3 | 4.8 |
| Shrub | 6 | 9.7 | 6 | 9.7 | 6 | 9.7 | 5 | 8.1 |
| Weedy Annual | 1 | 1.6 | 1 | 1.6 | 2 | 3.2 | 2 | 3.2 |
| Open Water | | | 1 | 1.6 | 3 | 4.8 | 9 | 14.5 |

TABLE 5. RECLASSIFICATION OF GROUND SAMPLING DATA BETWEEN 1974 AND 1977 USING SUBJECTIVE CLASSIFICATION

| Community in 1974 | No. of stations 1974 | No. of stations 1977 | Relative % | Community in 1977 |
|---|---|---|---|---|
| *Carex lacustris* | 15 | 1 | 6.7 | *Carex lacustris* |
| | | 4 | 26.7 | Open Water |
| | | 3 | 20.0 | Degraded *C. lacustris* |
| | | 2 | 13.3 | Weedy Annuals |
| | | 3 | 20.0 | *Carex stricta* |
| | | 1 | 6.7 | Degraded *C. stricta* |
| | | 1 | 6.7 | Emergents |
| *Carex stricta* | 15 | 5 | 33.3 | *Carex stricta* |
| | | 9 | 60.0 | Degraded *C. stricta* |
| | | 1 | 6.7 | Transition |
| Transition | 12 | 1 | 8.3 | Transition |
| | | 5 | 42 | Emergents |
| | | 4 | 33 | Degraded Transition |
| | | 2 | 17 | Open Water |
| Emergents | 11 | 2 | 18 | Emergents |
| | | 6 | 55 | Degraded Emergents |
| | | 3 | 27 | Open Water |
| Shrubs | 6 | 5 | 83 | Shrubs |
| | | 1 | 17 | *Carex stricta* |
| *Spiraea* | 3 | 3 | 100 | *Spiraea* |

of 12 (8.3%) retained the Transition classification whereas five (42%) changed to an Emergents classification and four (33%) to a Degraded Transition classification. The Emergents community showed the same trend toward reclassification as either Degraded or Open Water.

The subjective classification changes reflect a successional trend toward deeper water species, the result of deepening water levels in the marsh and continuing peat mat erosion. The *Carex lacustris* community which grew close to the cooling lake dike (in the area of greatest upwelling) suffered the greatest damage, so that very little *Carex lacustris* remains. As erosion has continued and extended diagonally through the center of the study area, the deeper water Transition and Emergents communities also have suffered severe losses.

The *Carex stricta* community has survived better than the *Carex lacustris* community because of its tussock building character. Nonetheless, five of the 15 stations classified *Carex stricta* in 1974 were reclassified as Degraded *Carex stricta* by 1977. Least fragile were the shrubby communities since they do not respond as quickly to change as the grasses and forbs.

A chi square test for two independent samples (Siegal 1956) was used to compare classification results year by year (Table 6). The chi square test

TABLE 6. RESULTS OF CHI SQUARE TEST ON CLASSIFICATION RESULTS

| Type and year of Classification | Not significant | 0.10 | 0.05 | 0.02 | 0.001 |
|---|---|---|---|---|---|
| Subjective classification | | | | | |
| 1974 to 1975 | x | | | | |
| 1975 to 1976 | | | x | | |
| 1976 to 1977 | x | | | | |
| 1974 and 1977 | | | | | x |
| 1974, 1975, 1976, 1977 | | | | | x |
| Association analysis | | | | | |
| 1974 to 1975 | x | | | | |
| 1975 to 1976 | | x | | | |
| 1976 to1977 | | | | | x |
| 1974 and 1977 | | | | | x |
| 1974, 1975, 1976, 1977 | | | | | x |
| Vegetation structure analysis | | | | | |
| 1974 to 1975 | x | | | | |
| 1975 to 1976 | x | | | | |
| 1976 to 1977 | x | | | | |
| 1974 and 1977 | | | | x | |
| 1974, 1975, 1976, 1977 | | | | | x |

for two independent samples can be performed if two criteria are met: 1) expected values are > 5.0; and 2) expected values of < 5.0 but > 1.0 are permitted in only 20% of the cases being considered in the test.

To meet these criteria, vegetation classes had to be combined. The vegetation classes used to compute chi square were Sedges (*Carex stricta* and *C. lacustris*), Degraded Sedges, Transition, Emergents, Shrubs, Other Disturbance (which takes in all Degraded categories other than Degraded Sedges), Open Water and Weedy Annuals.

The chi square tests indicate that the change that took place between 1975 and 1976, as recorded by the subjective classification, is significant at the 0.05 level. A chi square comparison of the 1974 and 1977 classifications is significant at the 0.001 level; so is the chi square test performed on the classification results for the 4 yr.

Figure 9 shows the spatial locations of the 62 study site sampling stations and their subjective classifications for 1974, 1975, 1976, and 1977. Over these years, the northern section of the study site became badly disturbed and changed from a Sedges classification to a Degraded Sedges or Open Water classification. The central section of the study area, which was classified Transition in 1974, became an Emergents area. In the southern section of the study site, stations initially classified as Sedges were reclassified as Degraded Sedges, Weedy Annuals, or Open Water. Only the southernmost stations escaped destruction.

## Association Analysis

Association analysis (Williams and Lambert 1959, 1960) was used to generate an objective classification of field data covering a 3-yr period.

This association analysis method differs from a subjective classification in that the classification of the data from each station is done using a computer program with set classification criteria. The user selects the method of classification to be used and various options within that method but the method is carried out by a computer program. Consequently the method is more consistent, although not necessarily as exact as subjective classification.

The association analysis was done using program DIVIDE found in the Clustan Manual (Wishart 1970), a computer package of several association analysis methods available at the Madison Area Computing Center.

To use association analysis, one cluster, containing data from all 62 sampling stations, is divided into two clusters of maximum species dissimilarity. Dissimilarity is based on whether each sample contains a particular species or not. The species used to divide the cluster is one that will create the greatest species dissimilarity in the resulting two clusters, using as a dissimilarity coefficient, sum chi square.

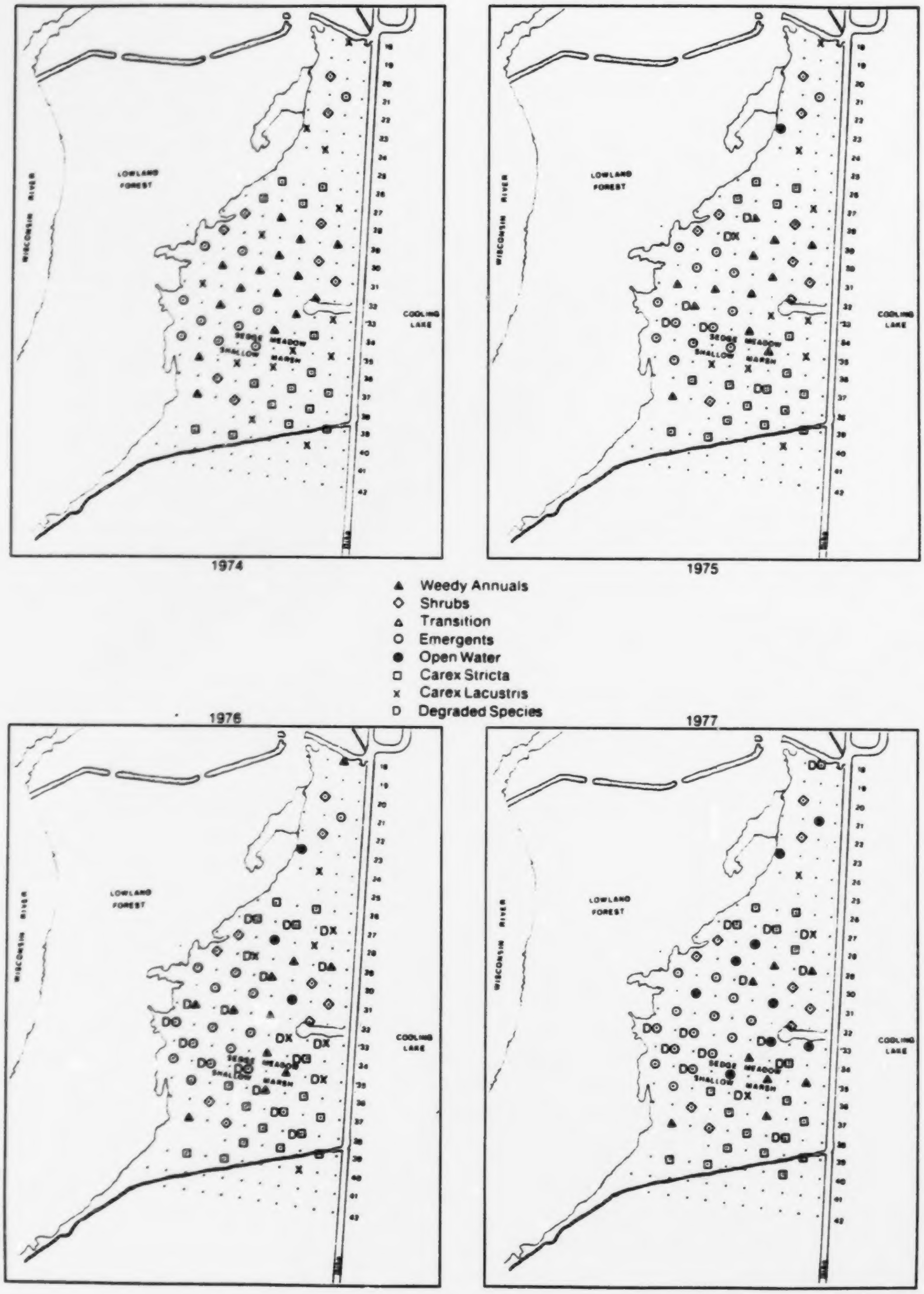

1974
1975
1976
1977
LOWLAND FOREST
WISCONSIN RIVER
COOLING LAKE
SEDGE MEADOW
SHALLOW MARSH
▲ Weedy Annuals
◇ Shrubs
△ Transition
○ Emergents
● Open Water
□ Carex Stricta
x Carex Lacustris
D Degraded Species

Figure 9. Subjective classification of ground sampling data in 1974, 1975, 1976 and 1977.

Once the first cluster is divided, one of the two new groups is termed positive. The positive group includes all sampling stations that contain the species used to create the original division. The other group is termed negative since the dividing species is absent from it. Division then continues along the positive branch until a statistically optimum number of clusters is reached. In this case, the optimum was 20 clusters. Division then takes place along the negative branch until a complete hierarchic division is obtained. A dendrogram (Figure 10) is a convenient way to show the species used to make the division in the analysis.

Program DIVIDE (an association analysis method) uses only binary data (presence-absence data expressed as 1 or 0 respectively). ("M" binary attributes are measured for population of "N" objects.) The ground sampling data for each year, 1974 to 1977, consisted of 62 objects (in this case sampling stations) while 34 attributes (selected species) were considered. The species selected for this analysis were those believed to be visually dominant in terms of height, cover and/or number, and responsible for the patterns seen on airphotos of the study site. The cost of this method depends on the size of the matrix created by multiplying attributes by objects. Since these 34 species are fairly common, enough information about them existed to have them be useful. Table 7 lists the 34 species used in the association analysis.

In order to compare the results of the association analysis with the subjective classification, the same vegetation classes (*Carex stricta*, Transition, etc.) were used for both analyses. For the purposes of this comparison, an additional class, Emergents-Open, was added to the association analysis since these two communities often were not separated using this method. Table 8 gives the results of the association analysis. As with the subjective classification, the association analysis is repeated for each year's data. The changes in clusters reflect the vegetation changes in the wetland (see Appendix E).

Using association analysis, stations classified as *Carex stricta* decreased from 27% of the total in 1974 to 9.7% in 1977 while stations classified as *Carex lacustris* decreased from 32% in 1974 to none in 1977 (Table 8). Stations classified as Sedges decreased from 60% of the total in 1974 to 9.7% in 1977. Stations classified as Transition decreased from 20% of the total to 4.8% in 1977. The number of stations classified as Emergents increased slightly from 9.7% to 13% for the same period of time. Stations classified as Degraded increased from zero in 1974 to 64% in 1977. The number of stations classified as shrubby remained stable while stations classified Open Water and Degraded increased from zero in 1974 to 64% in 1977.

Table 9 shows the 1974 classification of the 62 sampling stations and how those stations were reclassified in 1977. Forty percent of the stations originally classified *Carex lacustris* in 1974 were reclassified as Degraded *Carex stricta* in 1977. Although four (24%) of the stations classified *Carex stricta* in 1974 retained this classification in 1977, 58% were reclassified as Degraded *Carex stricta*. Two-thirds of the stations classified Emergents

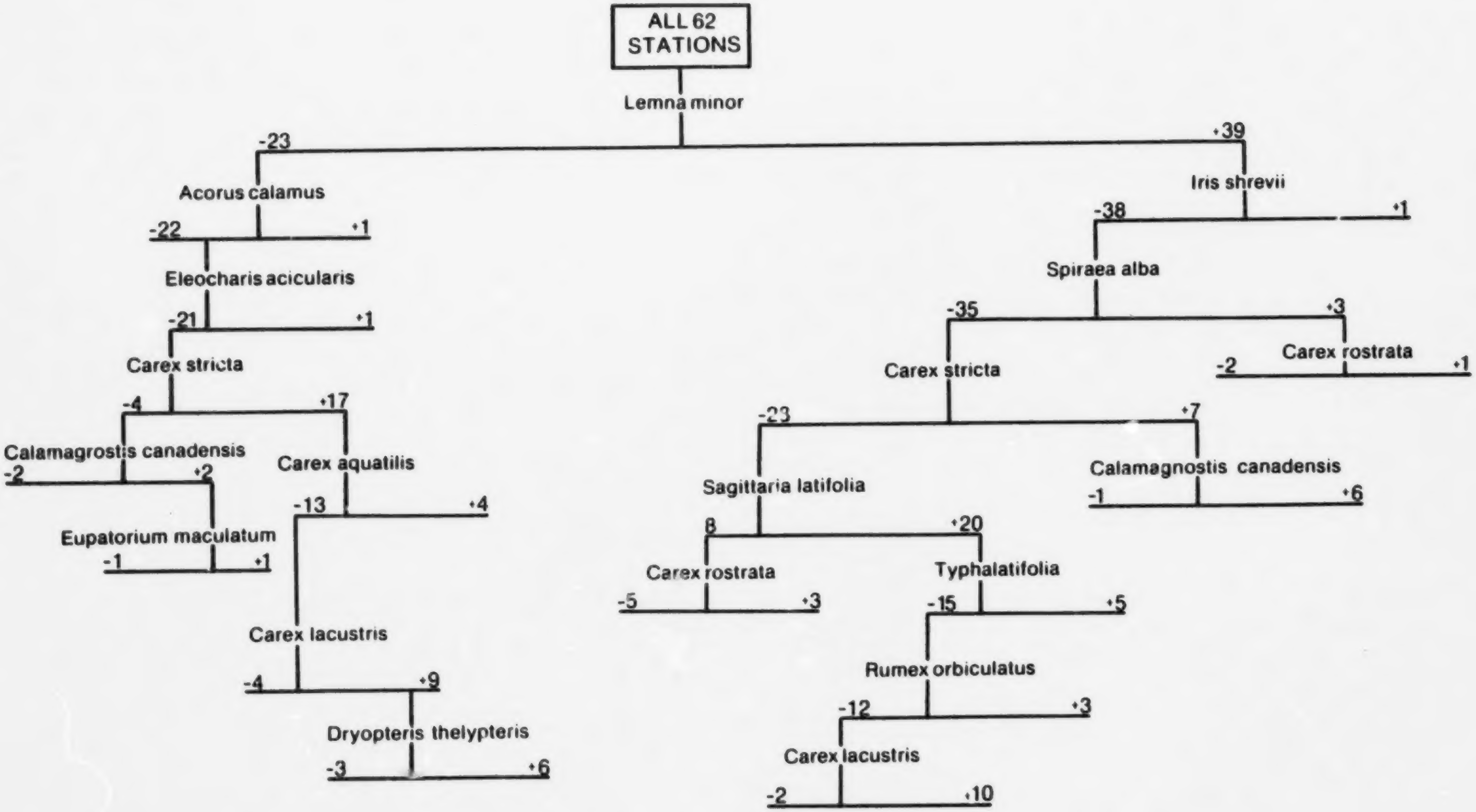

ALL 62 STATIONS
Lemna minor
-23
+39
Acorus calamus
-22
+1
Eleocharis acicularis
-21
+1
Carex stricta
-4
+17
Calamagrostis canadensis
-2
+2
Eupatorium maculatum
-1
+1
Carex aquatilis
-13
+4
Carex lacustris
-4
+9
Dryopteris thelypteris
-3
+6
Iris shrevii
-38
+1
Spiraea alba
-35
+3
Carex rostrata
-2
+1
Carex stricta
-23
+7
Calamagnostis canadensis
-1
+6
Sagittaria latifolia
8
+20
Carex rostrata
-5
+3
Typhalatifolia
-15
+5
Rumex orbiculatus
-12
+3
Carex lacustris
-2
+10

Figure 10. Dendrogram of ground sampling data by association analysis in the fall of 1976.

TABLE 7. THIRTY-FOUR VISUALLY DOMINANT SPECIES (ATTRIBUTES) USED IN THE ASSOCIATION ANALYSIS

1. *Acorus calamus*
2. *Calamagrostis canadensis*
3. *Carex aquatilis*
4. *Carex stricta* group
5. *Carex haydenii*
6. *Carex lacustris*
7. *Carex lasiocarpa*
8. *Carex rostrata*
9. *Dryopteris thelypteris*
10. *Eupatorium maculatum*
11. *Eupatorium perfoliatum*
12. *Helianthus grossesserratus*
13. *Iris shrevei*
14. *Leersia oryzoides*
15. *Lemna minor*
16. *Onoclea sensibilis*
17. *Polygonum coccineum* and *Polygonum natans*
18. *Rumex orbiculatus*
19. *Sagittaria latifolia*
20. *Scirpus cyperinus*
21. *Scirpus fluviatilis*
22. *Scirpus validus*
23. *Solidago gigantea*
24. *Spartina pectinata*
25. *Sparganium eurycarpum*
26. *Spiraea alba*
27. *Typha latifolia*
28. *Bidens cernua* and *Bidens coronata*
29. *Eleocharis acicularis*
30. *Sciprus americanus*
31. *Scirpus atrovirens*
32. Open water
33. *Cornus stolonifera*
34. *Salix* spp.

TABLE 8. SUMMARY OF ASSOCIATION ANALYSIS RESULTS

| Vegetation class | 1974 No. of stations | 1974 Relative % | 1975 No. of stations | 1975 Relative % | 1976 No. of stations | 1976 Relative % | 1977 No. of stations | 1977 Relative % |
|---|---|---|---|---|---|---|---|---|
| *Carex stricta* | 17 | 27 | 19 | 31 | 14 | 23 | 6 | 9.7 |
| Degraded *Carex stricta* | | | | | 10 | 16 | 18 | 29 |
| *Carex lacustris* | 20 | 32 | 9 | 14 | 2 | 3.7 | | |
| Degraded *Carex lacustris* | | | | | | | | |
| Transition | 12 | 19 | 15 | 24 | 11 | 18 | 3 | 4.8 |
| Degraded Transition | | | | | | | 4 | 6.5 |
| Emergents | 6 | 9.7 | 13 | 21 | 14 | 23 | 8 | 13 |
| Degraded Emergents[a] | | | | | | | 13 | 21 |
| *Spiraea* | 3 | 4.8 | 2 | 3.2 | 2 | 3.2 | 1 | 1.6 |
| Shrubs | 4 | 6.5 | 4 | 6.5 | 4 | 6.5 | 4 | 6.5 |
| Weedy Annuals | | | | | 1 | 1.6 | 5 | 8.0 |
| Open Water | | | | | 4 | 6.5 | | |

[a] Includes *Degraded Emergents* and *Open Water*. Association analysis did not successfully differentiate these two classes.

### TABLE 9. RECLASSIFICATION OF GROUND SAMPLING DATA USING ASSOCIATION ANALYSIS

| Community in 1974 | No. of stations | No. of stations | Relative percent | Community in 1977 |
|---|---|---|---|---|
| *Carex lacustris* | 20 | 0 | 0.0 | *Carex lacustris* |
| | | 8 | 40 | Degraded *Carex stricta* |
| | | 3 | 15 | Emergents-open |
| | | 3 | 15 | Degraded transition |
| | | 2 | 10 | Transition |
| | | 2 | 10 | Weedy annuals |
| | | 1 | 5.0 | Emergents |
| | | 1 | 5.0 | Degraded transition |
| *Carex stricta* | | 4 | 23 | *Carex stricta* |
| | | 10 | 58 | Degraded *Carex stricta* |
| | | 1 | 5.9 | *Spiraea* |
| | | 1 | 5.9 | Weedy annuals |
| | | 1 | 5.9 | Shrub |
| Transition | 12 | 1 | 8.3 | Transition |
| | | 1 | 8.3 | Degraded transition |
| | | 1 | 50 | Emergents-open |
| | | 4 | 33 | Emergents |
| Emergents | 6 | 2 | 33 | Emergents |
| | | 4 | 67 | Emergents-open |
| Shrub | 4 | 2 | 50 | Shrubs |
| | | 2 | 50 | Emergents-open |
| *Spiraea* | 3 | 2 | 67 | *Carex stricta* |
| | | 1 | 33 | *Spiraea* |

in 1974 were reclassified as Emergents-Open in 1977 and 50% of the stations classified as shrubby in 1974 were reclassified as Emergents-Open Water in 1977.

The association analysis method of classification shows (like the subjective classification) that the *Carex lacustris*, Transition, and Emergents communities are more fragile than the *Carex stricta* and shrubby communities.

Figure 11 shows spatially the classification changes, based on the association analysis, of the 62 sampling stations between 1974 and 1977.

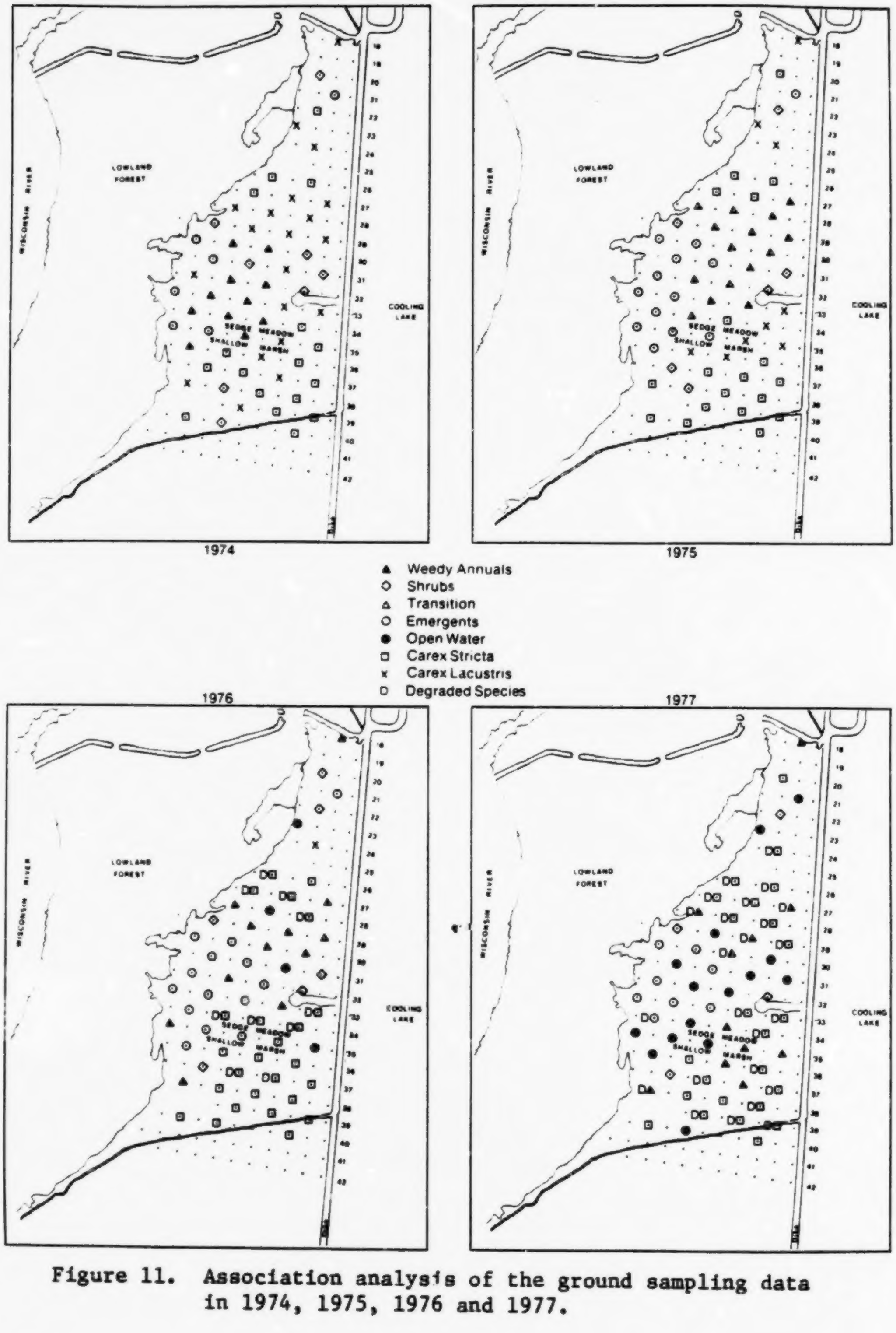

1974
1975
1976
1977
LOWLAND FOREST
WISCONSIN RIVER
COOLING LAKE
SEDGE MEADOW
SHALLOW MARSH
▲ Weedy Annuals
◇ Shrubs
△ Transition
○ Emergents
● Open Water
□ Carex Stricta
x Carex Lacustris
D Degraded Species

Figure 11. Association analysis of the ground sampling data in 1974, 1975, 1976 and 1977.

Results show the same trends as those obtained with the subjective classification. Areas classified as sedges in the northern and central areas of the site evolved to either a Degraded Sedges or Open Water classifcation by 1977. The large central area, originally classified Transition, converted to emergents and open water. The area along the west edge of the study site containing emergents expanded over 3 yrs while the sedge area in the southern portion of the site evolved to a Degraded Sedges and Degraded Transition classification.

Chi square tests for two independent samples were done to compare classification results for association analysis year by year. The vegetation changes were significant except for the year spanning 1974 and 1975 (Table 6).

## Vegetation Structure Analysis

Another way to demonstrate change in the study area was to document changes in vegetative structure with time. Ground sampling data were assigned to five categories of vegetative structure:

1) Grasslike: includes fine textured sedges, grasses and forbs, 2 to 4 ft tall, viewed from the air, this type of vegetation growth creates a continuous cover with no apparent gaps.

2) Tall-Coarse: includes species 4 to 8 ft tall with 50:50 or greater ratios of water to vegetation. This type of vegetation includes cattails and bulrushes and creates a coarse texture on airphotos.

3) Grasslike-Tall: includes sedge and grass species together with the emergent species described under Tall-Coarse. Vegetation classified as Grasslike-Tall displays more interspersion than vegetation classified as Grasslike.

4) Shrubby: includes predominantly shrubby species mixed with small, lowland trees.

5) Open: describes areas containing at least 75% water. When it does occur, rooted vegetation is very sparse. *Lemna minor* is included in Open.

Table 10 shows that stations classified Grasslike decreased over 3 yrs from 47 to 14.5% of the total. Stations classified Grasslike-Tall increased from 19% of the total to 24%, while stations classified Tall-Coarse increased from 19% to 29%. Stations classified shrubby remained stable in number. Stations classified Open increased from 1.6% of the total in 1974 to 19.4% in 1977.

Table 11 shows that more than two-thirds of the 29 stations classified Grasslike in 1974 were reclassified Grasslike-Tall or Open in 1977. By 1977 92% of those stations classified Grasslike-Tall in 1974 were reclassified

TABLE 10. SUMMARY OF VEGETATION STRUCTURE ANALYSIS RESULTS

| Structure class | 1974 |  | 1975 |  | 1976 |  | 1977 |  |
|---|---|---|---|---|---|---|---|---|
|  | No. of stations | Relative % | No. of stations | Relative % | No. of stations | Relative % | No. of stations | Relative % |
| Grasslike | 29 | 47 | 25 | 40 | 16 | 26 | 9 | 14.5 |
| Grasslike-Tall | 12 | 19 | 11 | 18 | 14 | 23 | 15 | 24.2 |
| Tall-Coarse | 11 | 18 | 14 | 23 | 15 | 24 | 18 | 29 |
| Shrubby | 9 | 14 | 9 | 14 | 9 | 14 | 8 | 12.9 |
| Open Water | 1 | 1.6 | 3 | 4.8 | 8 | 13 | 12 | 19.4 |

Tall-Coarse or Open. Of the 12 stations originally classified Tall-Coarse in 1974 73% retained that classification 4 yrs later, while 89% of the stations classified Shrubby in 1974 retained that classification. Table 11 demonstrates that the Grasslike and Grasslike-Tall classes were sensitive to impact and that the study area changed from a predominantly Grasslike and Grasslike-Tall vegetation structure to a Tall-Coarse and Open Water structure.

TABLE 11. RECLASSIFICATION OF GROUND SAMPLING DATA USING VEGETATION STRUCTURE ANALYSIS

| Community in 1974 | No. of stations 1974 | No. of stations 1977 | Relative % | Community in 1977 |
|---|---|---|---|---|
| | | 8 | 28 | Grasslike |
| Grasslike | 29 | 14 | 48 | Grasslike-Tall |
| | | 1 | 3.4 | Tall-Coarse |
| | | 6 | 20.3 | Open Water |
| | | 1 | 8.3 | Grasslike-Tall |
| Grasslike-Tall | 12 | 9 | 75 | Tall-Coarse |
| | | 2 | 17 | Open Water |
| Tall-Coarse | 11 | 8 | 73 | Tall-Coarse |
| | | 3 | 27 | Open |
| Shrubby | 9 | 8 | 89 | Shrubby |
| | | 1 | 11 | Grasslike |
| Open Water | 1 | 1 | 100 | Open |

A chi square test indicated that the changes recorded for 1974 to 1977 were significant at the 0.02 level. A chi square test performed on the data from all 3 yrs was significant at the 0.001 level (Table 6).

## Summary of Ground Sampling Data Methods

The diversity index demonstrated a 29% loss of species between 1974 and 1977. This technique detected changes in numbers of species present, year by year. It should be emphasized that the diversity index was useful in documenting changes at the Columbia study site where there was marked overall loss of species present. The diversity index would not work in disturbance situations where some species decreased but other species invaded or increased, resulting overall in no change or an increase in the number of species. The diversity index is the only method of the nine methods discussed which deals exclusively with species change.

Classification Methods--

Tables 4, 8, and 10 show changes in the numbers of sampling stations assigned to each vegetation class over 4 yr. All herbaceous classes showed losses in numbers, while the number of stations classified as Open Water increased dramatically. Only the shrubby classes tended to remain constant. Using the methods of subjective classification, association analysis and vegetation structure classification, 28%, 15%, and 42% respectively of the sampling stations retained their original classification over 3 yr.

Tables 5, 9, and 11 show how the vegetation at specific stations changed with time. Almost all stations classified as *Carex lacustris* in 1974 changed to a Degraded Carex stricta or Open-Emergents classification by 1977. (The *Carex lacustris* community has almost entirely disappeared from the study site.)

The *Carex stricta* community survived somewhat better than the *Carex lacustris* community. Twenty-three to 33% (depending on the classification method) of those stations classified *Carex stricta* in 1974, still retained that classification in 1977. *Carex stricta* stations were most frequently reclassified as Degraded *Carex stricta*.

The Transition community is as fragile as the *Carex lacustris* community. Only 8% of the stations classified Transition in 1974 retained this classification in 1977. Most Transition stations were reclassified as Emergents or Open Water by 1977.

The Emergents community appeared to only be slightly less fragile than the Transition community. Using subjective classification, 82% of those stations classified as Emergents in 1974 had gone to a Degraded Emergents or Open Water classification by 1977. Using association analysis 67% of the stations originally classified as Emergents had gone to an Emergents-Open classification.

Only the Shrubs and *Spiraea* communities retained their species integrity. All other communities changed, at the very least, to a degraded classification. Substantial numbers of stations from all communities were reclassified as Emergents, Degraded Emergents, or Open Water after 3 yr. This reflects the widespread erosion of the peat mat and the consequent widespread destruction of most of the marsh/sedge meadow species.

Change of classification of each of the 62 sampling stations was compared for 1974 to 1975, 1974 to 1976, and 1974 to 1977 using each of the three ground sampling classification methods. Table 12 shows the percentage of sampling stations which changed their classification using the methods of subjective classification, association analysis, and vegetation structure analysis.

TABLE 12. SAMPLING STATIONS CHANGING THEIR CLASSIFICATION 1974-75, 1974-76, AND 1974-77

| Classification method | 1974-75 % | 1974-76 % | 1974-77 % |
|---|---|---|---|
| Subjective classification | 19 | 52 | 60 |
| Association analysis | 47 | 64 | 79 |
| Vegetation structure analysis | 19 | 48 | 55 |

The amount of change shown by each of the three classification methods is partly an artifact of each method. The association analysis classification method shows the greatest amount of change in sampling station classification. Association analysis defines vegetation classes using presence-absence data based on one species at a time. According to this method, if a sampling station lacks one species which is being used to form a particular cluster even though it contains all the other prominent species which define that community, it will not be identified as belonging to that community. All sampling stations classified as a cluster using this association method must be given the same classification, even though they might be labeled differently using subjective classification. But association analysis has several advantages. Once the type of analysis and options are selected, the analysis is consistent and objective. And association analysis can handle large quantities of data in far less time and at less cost than subjective classification.

Subjective classification offers the most finely tuned classification because 1) it is based on species stem counts data which offer more information than is available with binary data, and 2) it offers greater data-analyst interaction. Its greatest shortcoming is lack of objectivity. In using this method the analyst must be careful to set up and adhere strictly to specific criteria for each vegetation class.

The vegetation structure classification method is crude in comparison to the other two methods because it is based on changes in the types of vegetation structure rather than changes in either species stem counts or presence-absence data. For this classification technique, only five vegetation structures were defined in constrast to 12 vegetation classes which were defined using other methods. Furthermore, the character of the vegetation at a sampling station can change without its vegetation structure changing. For example, data classified as *Carex lacustris* could change to a Degraded *Carex lacustris* or a Degraded *Carex stricta* classification. Using vegetation structure analysis, these data initially would be classified Grasslike and would retain that classification.

The subjective classification and vegetation structure analysis methods indicate changes in sampling station classification as shown in Table 12, because the vegetation structure analysis used in this study was based on ground sampling stem counts data instead of the more appropriate percentage cover data.

The mapped results from the three types of classification provide a spot representation of changes in community area and location. The mapped classification results document the transition at the study site from more shallow water species to deeper water species and weedy mudflat species. These results also show that few of the original species other than shrubs can withstand the constantly expanding erosion and destruction of the peat mat in the central part of the study site.

In summary, whereas the diversity index analyzes ground sampling data at only the species level, the subjective classification and association analysis classify data by community type, based on the species found at each sampling station. It is the analyst's opinion that subjective classification is the more sensitive method since it uses species stem counts data, unlike association analysis which uses prresence-absence data. Vegetation structure analysis is a relatively crude classification tool. Its classification is based exclusively on vegetation structure data; consequently it cannot offer the degree of differentiation that species-based classification offers.

## USE OF AIRPHOTOS TO MONITOR CHANGE

A series of airphotos was analyzed using the methods of airphoto monitoring and disturbance mapping. Sequential airphotos permit the observation of changes in pattern, texture, color and other features that occur over time at a site.

### Factors Affecting Airphoto Interpretation of Wetlands

Wetland vegetation classes are easier to depict using color infrared film rather than color film (Brown 1978). With color film the many shades of green seen on summer imagery are too subtle for consistent and easy photo interpretation. Color infrared film better defines living vegetation in distinguishable shades of pink and red (Olson 1964, Gammon and Carter 1979). Water definition on wetland airphotos is particularly important. Color infrared film defines water, which appears a deep blue or black tone, more clearly than color film (Shima 1973, Gammon and Carter 1979).

Late spring and early fall are the best times to obtain airphotos of southern Wisconsin wetlands (Meyer 1977). At these times the spectral response patterns of various vegetation classes are still consistent but more easily distinguishable, one from another, than they are at midsummer. In the middle of summer all spectral response patterns are so saturated in the infrared-sensitive film layer than they are difficult to differentiate (Scher and Tueller 1973).

Color and texture were both critical elements in identifying vegetation classes. Since vegetation class color on airphotos changes with film type, processing, sun angle and vegetaton vigor, color could not be used over time to identify vegetation classes (Gallagher, Thompson and Reimold 1972). Color and texture were used simultaneously to identify vegetation classes (Whitman and Marcellus 1973).

Airphoto scales used were 1:120,000, 1:38,200, 1:19,100 and 1:11,500. The 1:120,000 scale is so small that texture could not be determined, depriving the analyst of important photo interpretation information. The 1:38,200 scale is adequate for vegetation mapping, however, a scale of 1:19,100 offers more textural and color detail. Figure 12 is an enlargement of a 5 October 1977 color infrared airphoto, original scale 1:11,500. At this scale of 1:11,500 so much color and texture detail is available that it becomes difficult to generalize it sufficiently to create a legible map. As the scale becomes larger, the problem of the same vegetation class appearing differently on an airphoto depending on the amount of vegetation-water interspersion becomes more acute (Olson 1964; Scher and Tueller 1973; Shima, Anderson and Carter 1976; Brown 1978).

## Airphoto Monitoring

Airphotos can be used without ground verification to monitor vegetation change with time at a site which is inaccessible from the ground (Hubbard and Grimes 1972). For best results, the airphotos should be taken at the same time of day. For easy comparison they should be taken at the same scale and at the same season or seasons each year.

A series of airphotos of the marsh/sedge meadow were taken from June 1972 to October 1977. All the photos are color infrared. All were taken in summer or early fall with the exception of the June 1977 color airphoto and three color photos taken on 1 March 1975, 1976, and 1977.

In general the pinkish red magenta tones of the color infrared airphotos taken from June to mid-September indicate actively synthesizing vegetation. (Reflectance in healthy vegetation increases dramatically from 0.7-1.3  m in the spectrum (Swain and Davis 1978).)

Light tan patches indicate areas on the color infrared film where the vegetation is dying back. On color infrared film, dead or dying vegetation does not have the intense pink-red tones characteristic of living vegetation. Tan patches are also indicators of disturbance on these color infrared airphotos. On color photos, dying vegetation shows a yellowish-tan tone.

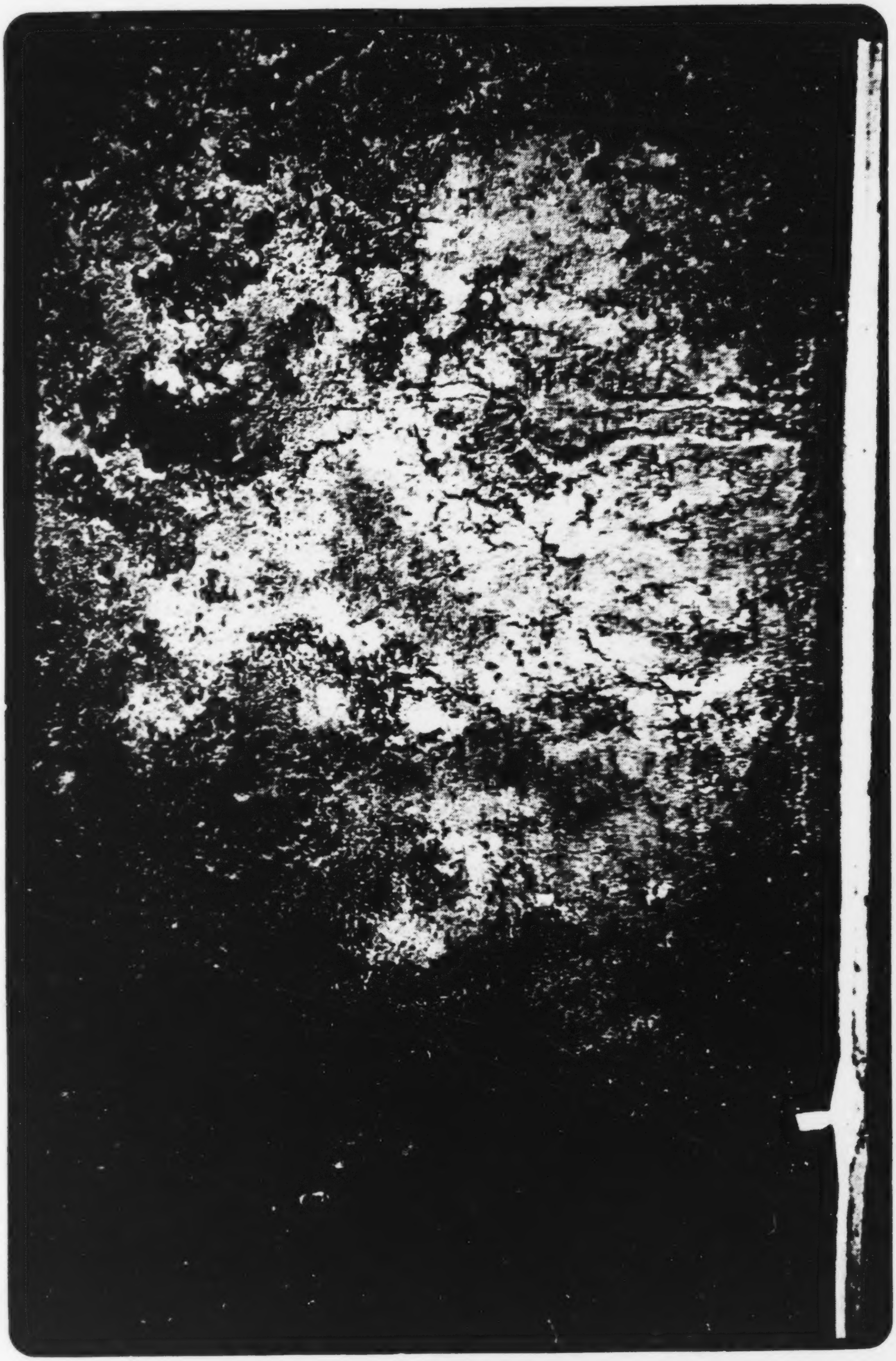


Figure 12. CIR airphoto used to determine airphoto grid size on October 3, 1977 (original scale 1:11,500).

Besides these general characteristics the following features can be accurately interpreted from airphotos with little or no ground verification.

1) Trees appear as the coarsest texture on the 11 airphotos in a deep magenta or intense red tone.

2) Marsh/sedge meadow appears as a red-pink, relatively smooth textured area between the trees to the west and the dike and cooling lake to the east.

3) Water appears as a deep blue or black. Initially it is visible in the river, and then in the cooling lake. Beginning in September 1975, the area of blue-black color increases in the study area as the peat mat erodes. As such, it is an indicator of disturbance.

4) Constructed surfaces are generally characterized by straight lines and a very high reflectance. The dike and the intake channel are easily identified as man-made features by their bright, whitish color and linear form. Another prominent man-made feature in the study area is the keyhole well, a keyhole shaped weedy, shrubby sand-dump area directly north of the overflow channel.

5) Sand has a very high reflectance; it appears tannish white on both color infrared and color airphotos.

6) *Lemna minor* (Duckweed) is a tiny surface floating plant with a very high reflectance which appears as whitish-pink patches within the marsh/sedge meadow on color infrared photos. Duckweed grows on shallow water where it can be exposed to nearly full or full sunlight. It is incompatible with sedges and grasses whose dense canopies effectively shade it out. In this study, duckweed is an indicator of disturbance. As more and more duckweed appears with time, it means vegetation which would shade it out is dying off, making increasing amounts of habitat available to it.

The 4 June 1972 airphoto (Figure 13), the earliest in the series, shows the sedge meadow before extensive degradation occurred. The airphoto from 31 July 1974 (Figure 14) shows the area 2 yrs later. Both photos are color infrared high altitude airphotos, original scale 1:120,000, and both show the marsh/sedge meadow forming a dense, continuous surface. Dark patches of open water are only visible near the lowland forest and in one area in the northern end of the study site.

The vegetation mat is still largely intact on a September 1975 color infrared airphoto (Figure 15), original scale 1:38,200. However, far more detail can be seen on this photo, made at a larger scale than the previous two. Keeping in mind that filling the cooling lake was started in January 1975, the increased surface water visible in this photo reflects the increased groundwater flowing into the area. Several light toned, almost whitish areas of duckweed (*Lemna minor*) can also be seen in Figure 15 indicating that duckweed has shown up in the marsh/sedge meadow where the peat mat has broken up. As such it is an indicator of disturbance.

Figure 13. CIR airphoto on June 4, 1972 (original scale 1:120,000).

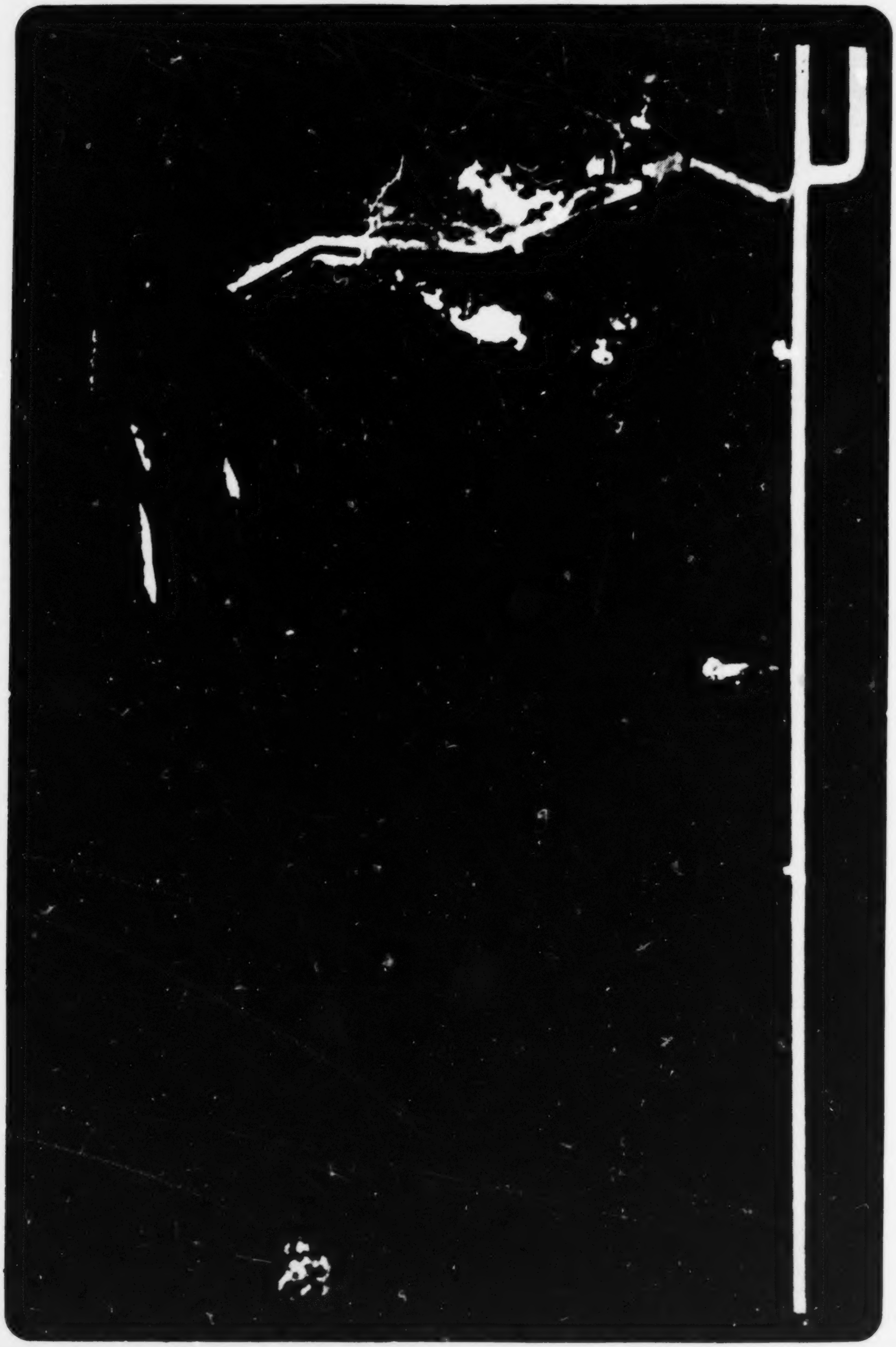


Figure 14. CIR airphoto on July 31, 1974 (original scale 1:120,000).

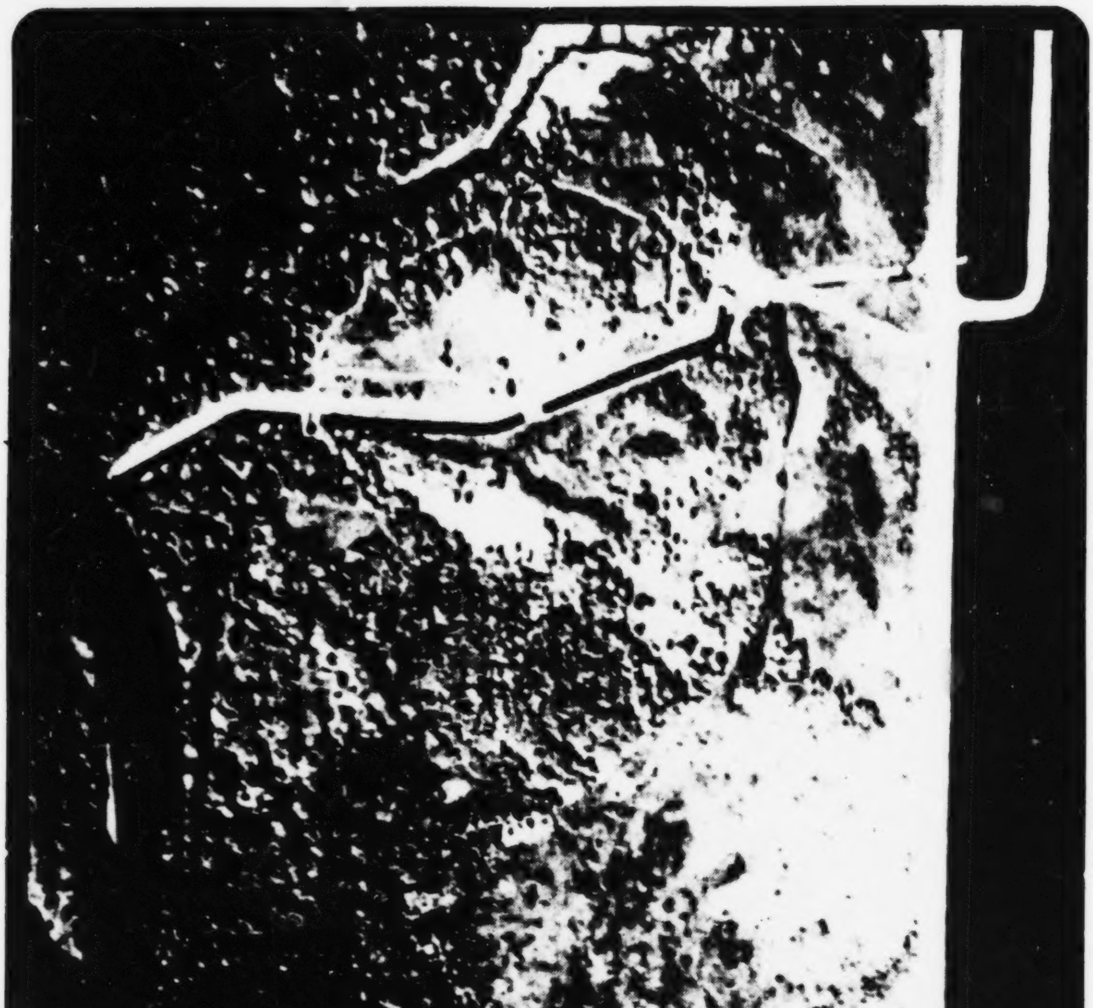


Figure 15. CIR airphoto on September 25, 1975 (original scale 1:38,200).

Figure 16, a 24 July 1976 color infrared airphoto (original scale 1:38,200) shows that areas of open water or water covered with duckweed now abound. Much of the northern section of the study site now appears to be highly disturbed. Some of the areas of very high reflectance (whitish pink tones) consist of floating and exposed peat, often covered with seedlings of annuals and a layer of duckweed. Dark green-blue black tones in the center of the study site indicate areas of standing water. In the lower center of the photo, a channel is beginning to form. An actual pond, characterized by considerable flow, is evident in the upper right-hand corner. The previous fall, this area was covered with duckweed. A large dark area in the lower left-hand corner of the photo consists of hydrophytic species widely interspersed with deeper water.

Comparing Figure 16 with Figures 14 and 15 reveals that the open water area in the upper right-hand corner (indicated by the arrow) has extended northward. Definite channels now flow from this open area through the tree island (extending from the upland out into the marsh) to join the large central channel. In addition, new areas of definite disturbance are appearing both west and east of that channel.

Figure 17, a photo made from a 24 September 1976 CIR airphoto, original scale 1:19,100, shows that the channel running along the north knoll and the channels flowing through the tree island are more clearly defined than 2 months earlier. Far more duckweed is in evidence south of the tree island and west and south of the keyhole well. The quantity of water in the west-central portion of the study site can be more easily seen than was possible on the July photo because this September photo is at a larger scale and also, the vegetation is dying back here. More open water is visible on this airphoto than could be seen in Figure 15, taken a year earlier.

Figure 18 is a photo made from a 25 June 1977 color infrared airphoto, original scale 1:38,200. This picture shows that a large channel has cut through the center of the study area while the channels along the north knoll have become localized. The pond where this channel ends has become enlarged.

Another airphoto from 25 June 1977 (Figure 19) is the same scale as the previous one but it is a color photo rather than color infrared. Although areas of dead vegetation show up strikingly in a tannish-white, areas of water are more difficult to detect on this photo. Nuances of color among the living vegetation are also far less discernible here than on the infrared photo.

Figure 20 is made from an October 1977 color infrared airphoto, original scale 1:11,500. This photo shows areas of open water continuing to enlarge. The central channel and the pond below it have widened. Most light areas are areas of disturbance and destruction. At this point in time, vegetation damage is fairly ubiquitous.

Figures 21, 22 and 23 were made from color airphotos taken on 1 March 1975, 1976, and 1977. The 1 March 1975 airphoto (original scale 1:19,100) was taken 2 months after the cooling lake was filled and before Unit I went

Figure 16. CIR airphoto on July 24, 1976 (original scale 1:38,200).

Figure 17. CIR airphoto on September 24, 1976 (original scale 1:19,100).

Figure 18. CIR airphoto on June 25, 1977 (original scale 1:38,200).

Figure 19. Color airphoto on June 25, 1977 (original scale 1:38,200).

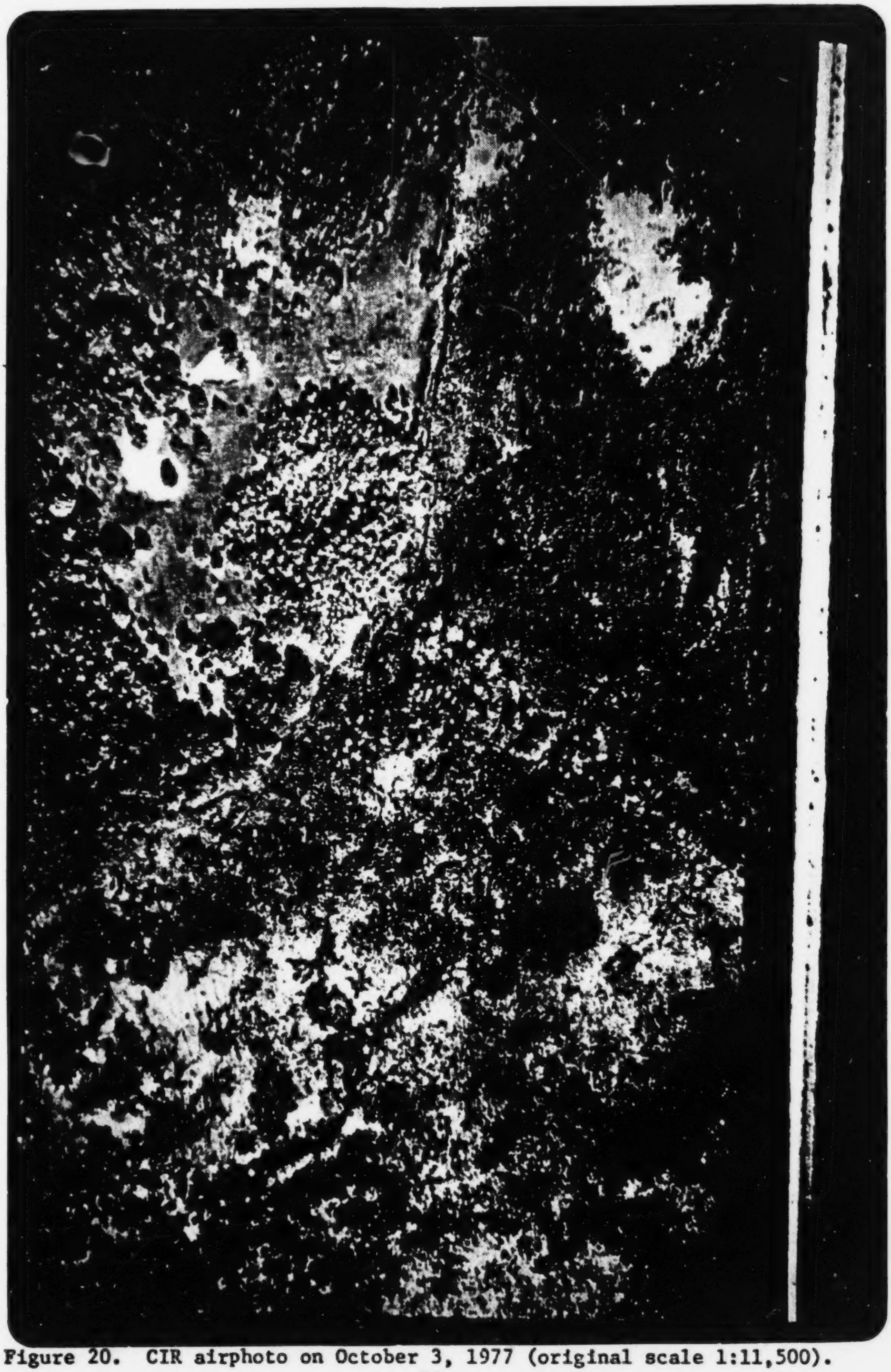


Figure 20. CIR airphoto on October 3, 1977 (original scale 1:11,500).

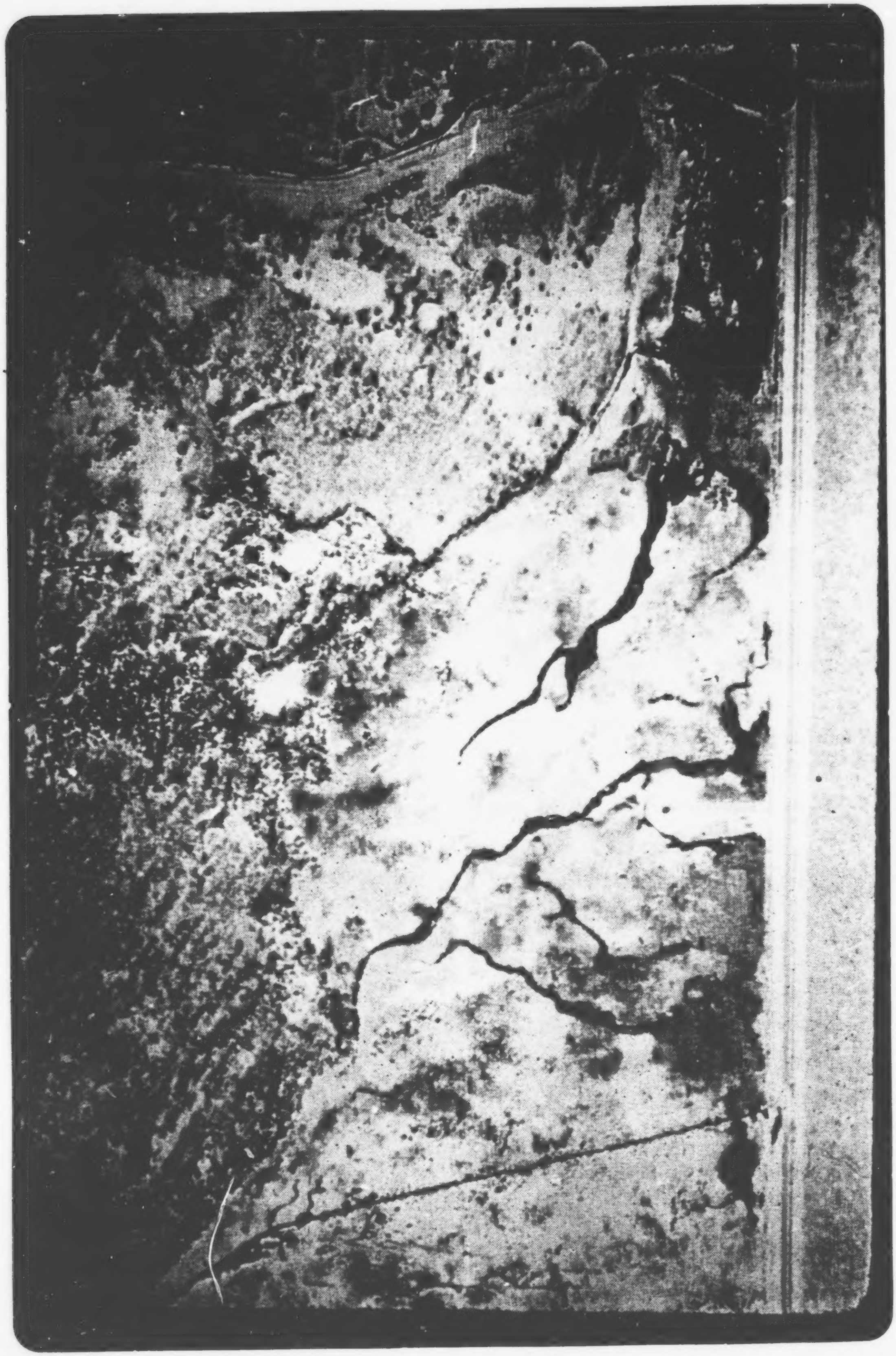


Figure 21. Color airphoto on March 1, 1975 (original scale 1:19,100).

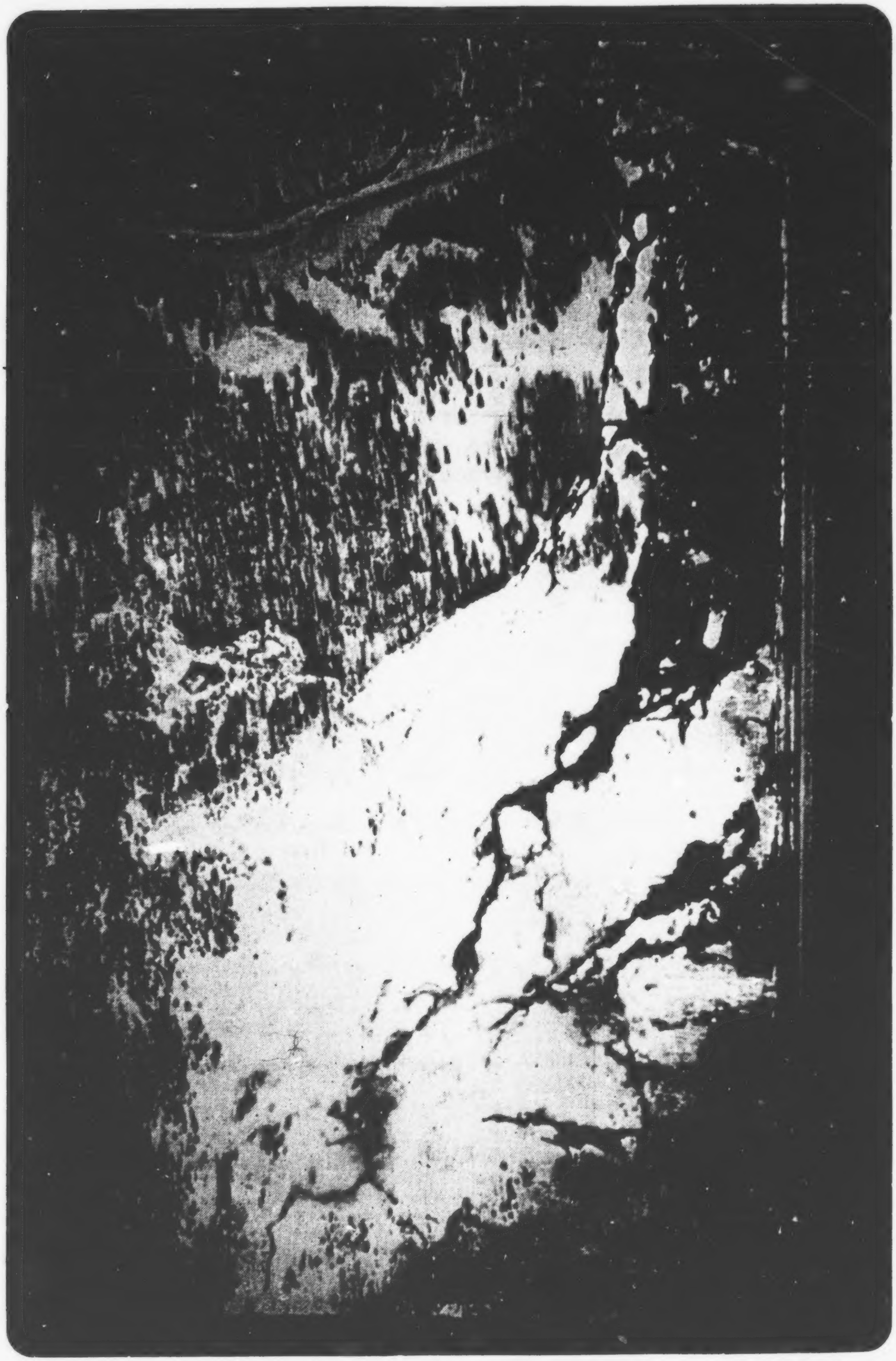


Figure 22. Color airphoto on March 1, 1976 (original scale 1:38,200).

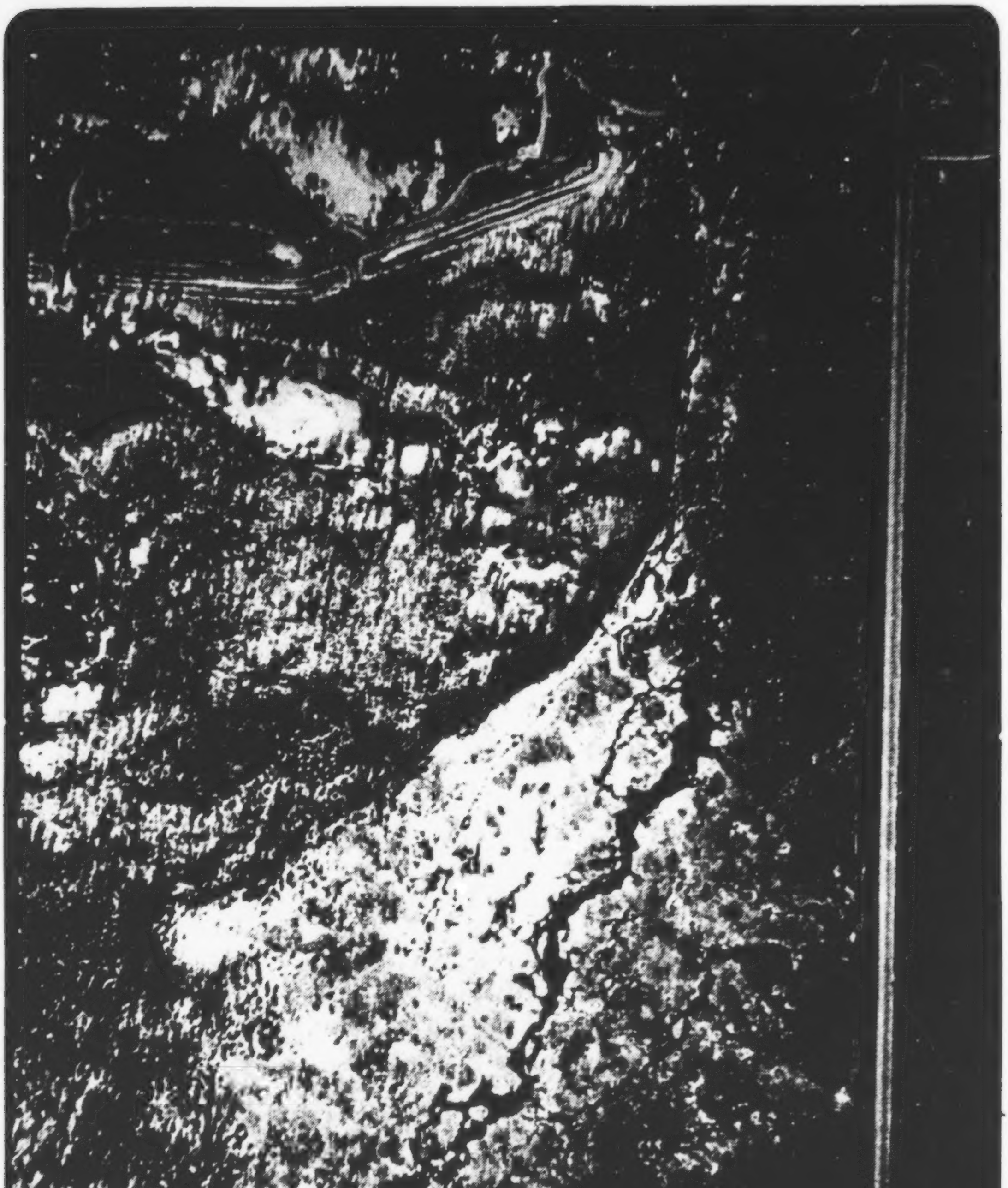


Figure 23. Color airphoto on March 1, 1977 (original scale 1:38,200).

on line. Once the cooling lake filled, increased ground water flowed into the already frozen marsh/sedge meadow, breaking through the frozen surface, spreading out and freezing into large sheets of ice.

The 1 March 1976 airphoto (Figure 22, original scale 1:38,200) shows much open surface water. The water was present, in part, because of a thaw that lasted from mid February through early March. In addition, however, the open ponds visible in the northern end of the study site and a substantial channel flowing from this area down into the rest of the study site provide evidence that substantial peat mat erosion continued throughout the winter months.

The 1 March 1977 photo (Figure 23, original scale 1:38,200) shows two open areas in the northern end of the study site, a definite channel flowing along the north knoll, and channels flowing down into the center of the study site.

On all three photos, ice and open water at the study site correspond with areas of significant disturbance where often the vegetation has died of exposure (Bedford 1977) and the peat mat has floated up. These three March airphotos provide important documentation of the channel cutting which continues throughout the winter at the study site. Open water is as clearly defined on these winter color photos as it is on winter color infrared photos but ice is more visible on the color photos. If the analyst were only concerned with monitoring open water, color infrared photos should be used exclusively (Niemann et al. 1975).

## Airphoto Interpreted Disturbance Maps

Airphoto interpreted maps were made outlining areas of disturbed and undisturbed vegetation and open water. This was done by enlarging selected color infrared photos 6.67 times and drawing the images that were identified on frosted mylar. Table 13 lists the dates and scales of the original imagery used to generate these maps.

TABLE 13. AIRPHOTOS USED TO TO GENERATE DISTURBANCE MAPS

| Date | Scale |
|---|---|
| 25 September 1975 | 1:38,200 |
| 24 September 1976 | 1:19,100 |
| 25 June 1977 | 1:19,100 |
| 3 October 1977 | 1:11,500 |
| 1 March 1975 | 1:19,100 |
| 1 March 1976 | 1:38,200 |
| 1 March 1977 | 1:38,200 |

A series of four vegetation disturbance maps were drawn which show Disturbed and Undisturbed areas and Open Water over a 3-yr period. Undisturbed areas are those areas which retained their original vegetation cover as recorded in September 1975. Disturbed areas are characterized by vegetation that has degraded due to peat mat erosion. Duckweed was generally found scattered among the vegetation in these areas and there are fewer of each species than in the Undisturbed areas. Open Water areas exist where ground water upwelling is so great it has worn a hole in the peat mat which continues to erode or where surface water flow is substantial enough to show open water on airphotos.

The 25 September 1975 map (Figure 24) shows only a few small areas of disturbed vegetation in the northern end of the study site. The only areas where open water is visible are the drainage ditch running across the study area and the channel along the far left edge of the study area.

Figure 25, a map drawn from a 24 September 1976 airphoto, shows how areas of disturbed vegetation and open water have both expanded. Disturbed vegetation has increased in the northern part of the study area and to the south and west. Definite pools and channels of open water are now in evidence, indicating places where the peat has disintegrated and the flow is so strong that *Lemna minor* (duckweed) cannot remain on the surface but is carried off downstream.

On the 25 June 1977 map (Figure 26) areas of open water and disturbed vegetation have expanded greatly, indicating that the peat mat has continued to erode and disintegrate. This map shows a definite channel forming from the northern end of the study area down to the southwest.

The map drawn from a 3 October 1977 airphoto (Figure 27) shows that the central channel has widened and become better defined. In this map, new areas of open water are appearing in areas that were classified disturbed in June 1977. And this map provides evidence that the disturbed area has increased considerably since June. By October 1977 much of the disturbed area was characterized by floating mat-mud flat; vegetation was largely absent.

Figures 28, 29, and 30 are maps that indicate open water, sheet ice, and snow cover. These maps were drawn from imagery taken 1 March 1975, 1 March 1976, and 1 March 1977 respectively. These maps are particularly interesting because they show the surface drainage patterns and the continuing erosion of the peat mat that are evident in winter.

The cooling lake was filled during January 1975 but the power plant did not go on-line until late March 1975. Consequently, during the winter of 1974-75, the study area had time to freeze before extensive leakage from the cooling lake could begin. This resulted in much open water and sheet ice on the surface at the northern and southern ends of the study site although leakage is heaviest at the northern end (Figure 28).

The map in Figure 29 (1 March 1976) reveals extensive open water at the northern end of the study site which later formed into the channel system

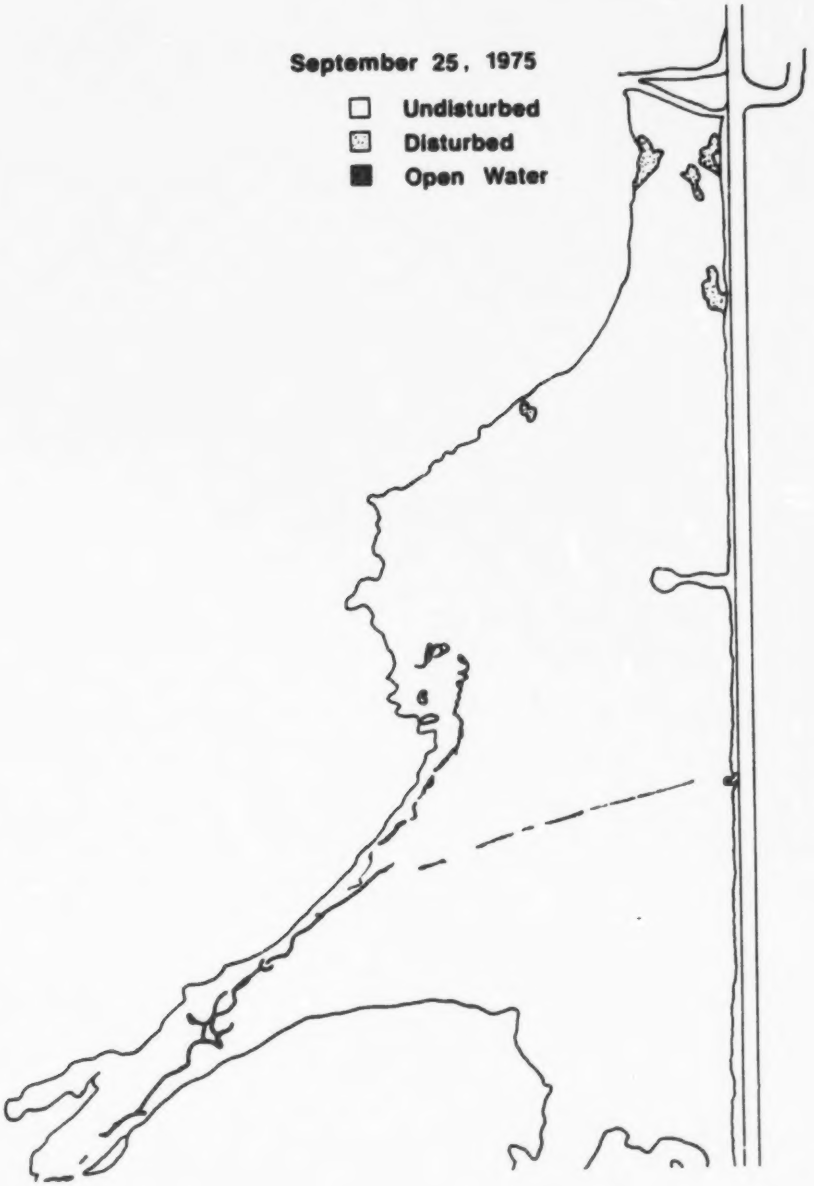

September 25, 1975
☐ Undisturbed
▨ Disturbed
■ Open Water

Figure 24. Disturbance map on September 25, 1975.

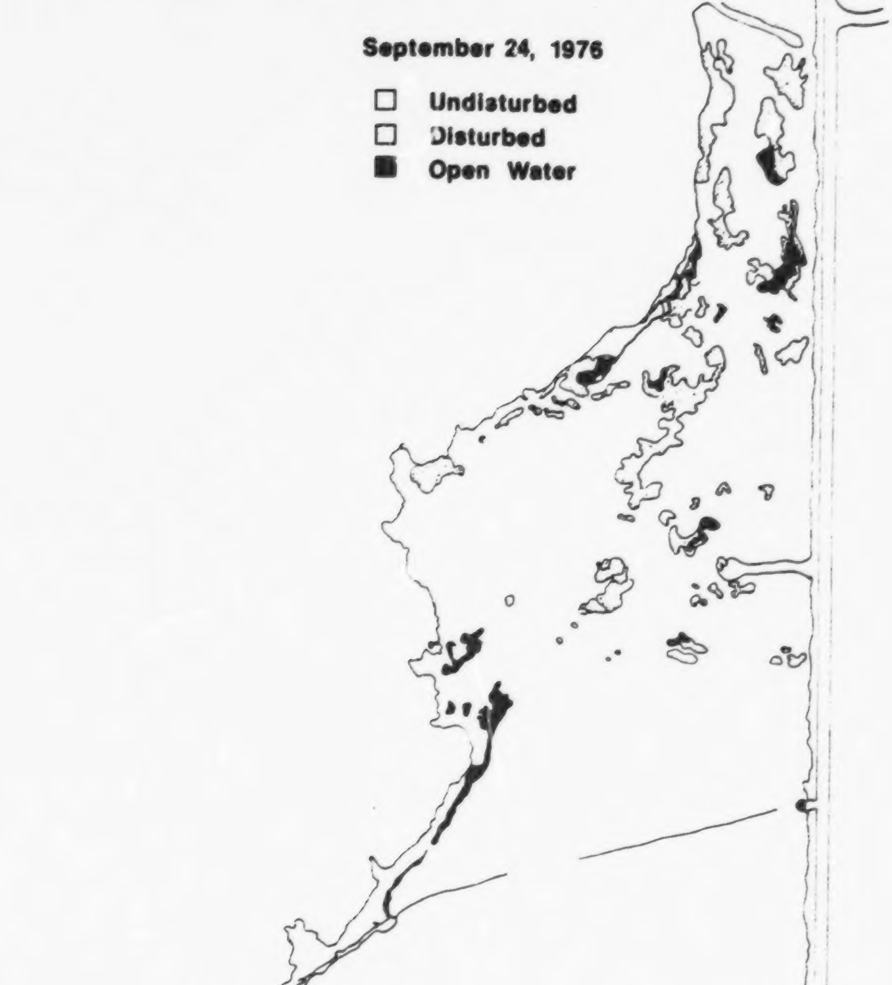

September 24, 1976
☐ Undisturbed
☐ Disturbed
■ Open Water

Figure 25. Disturbance map on September 24, 1976.

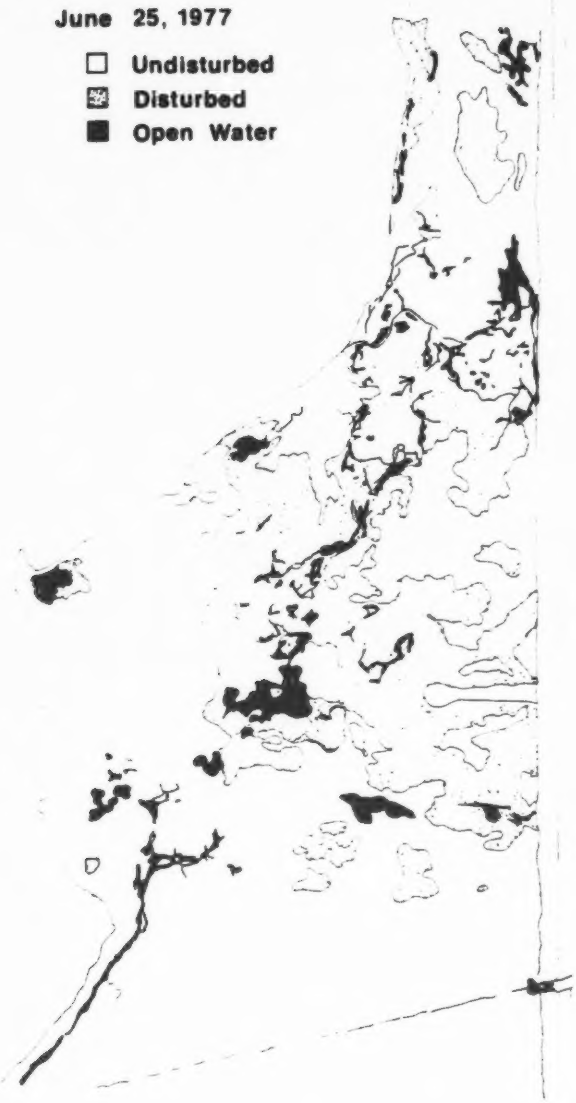

June 25, 1977
☐ Undisturbed
▨ Disturbed
■ Open Water

Figure 26. Disturbance map in June 25, 1976.

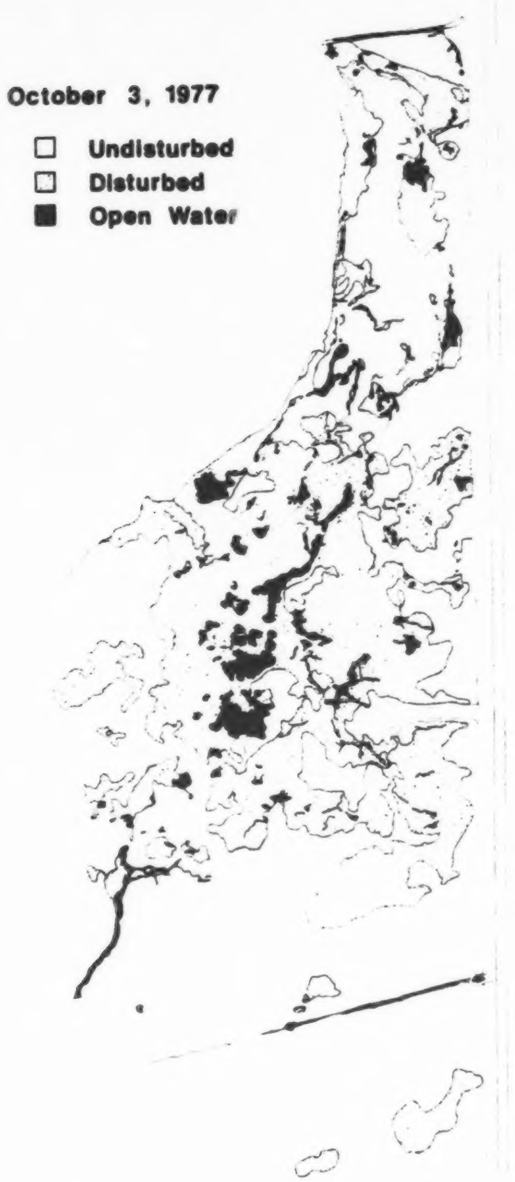

October 3, 1977
☐ Undisturbed
▨ Disturbed
■ Open Water

Figure 27. Disturbance map in October 3, 1977.

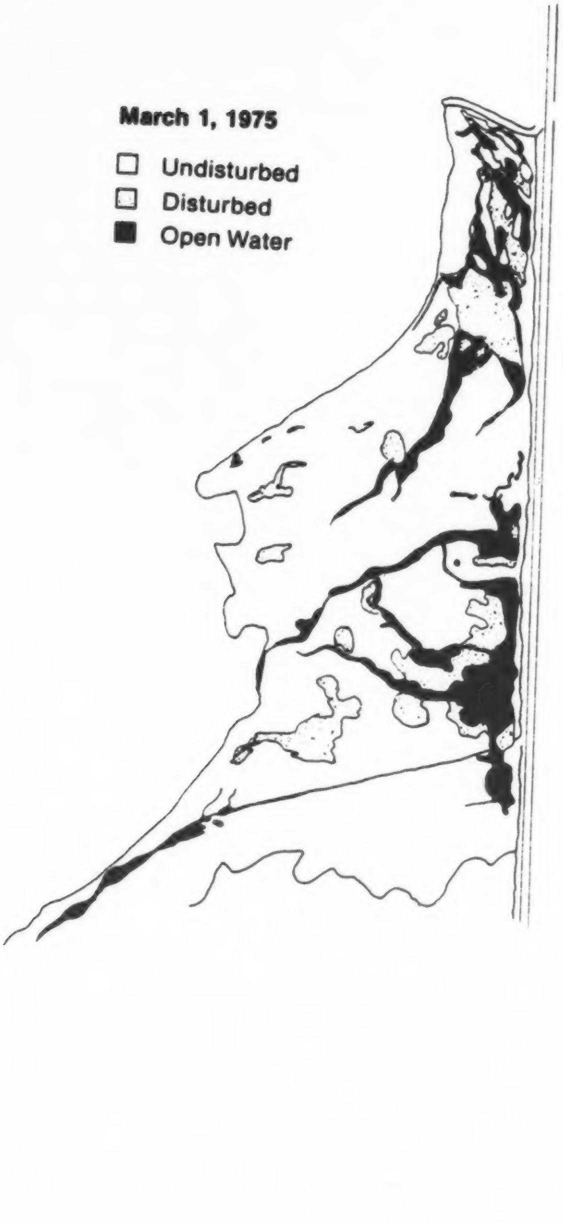

March 1, 1975
☐ Undisturbed
▨ Disturbed
■ Open Water

Figure 28. Disturbance map on March 1, 1975.

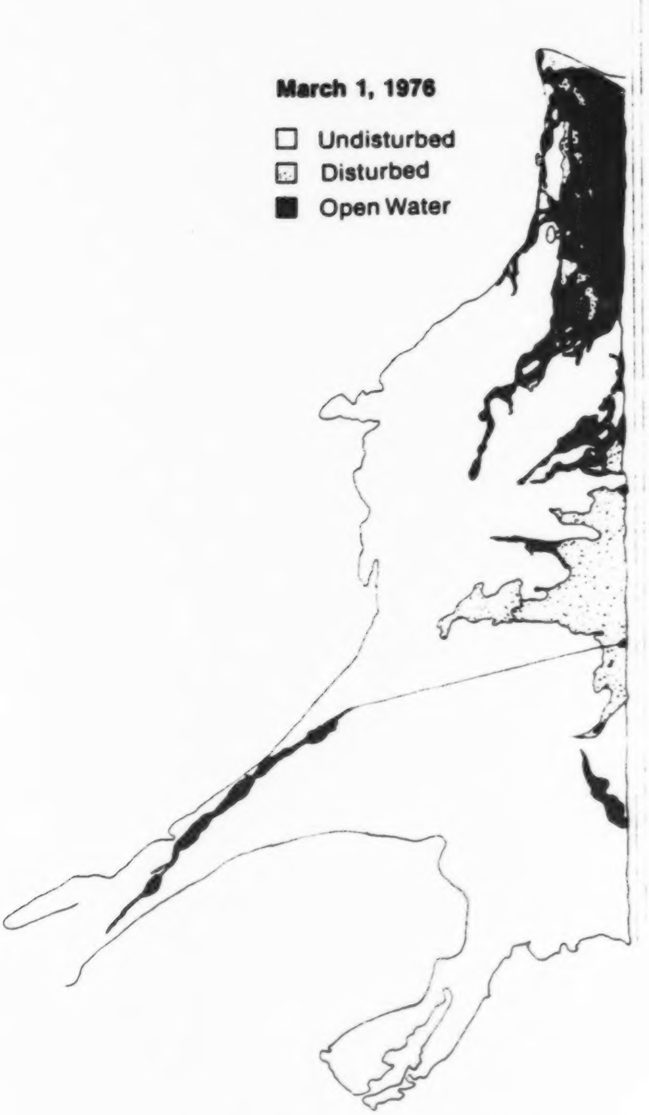

March 1, 1976
☐ Undisturbed
▨ Disturbed
■ Open Water

Figure 29. Disturbance map on March 1, 1976.

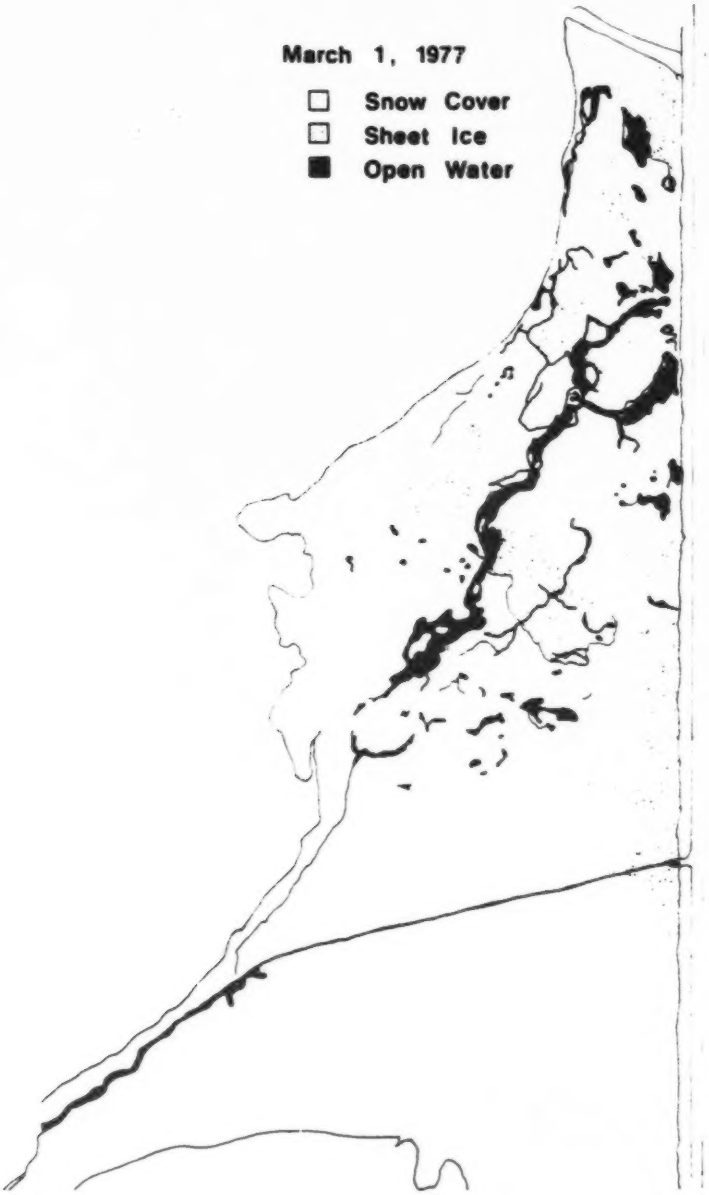

March 1, 1977
☐ Snow Cover
☐ Sheet Ice
■ Open Water

Figure 30. Disturbance map on March 1, 1977.

seen on both the September 1976 and June 1977 maps. (Water moving out from the cooling lake was heated at this point in time.) In the southern end of the study site where leakage from the cooling lake is reduced, extensive surface ice has formed.

The 1 March 1977 map (Figure 30) shows how the open water channel has continued to develop over a year's time, draining off most of the open water in the northern end of the study site. Surface ice, extensive over much of the study site, correlates with the areas of disturbance delineated on the June and October 1977 maps (Figures 26 and 27).

### Summary of Airphoto Data Methods

Airphoto monitoring consists of obtaining a series of airphotos at the same site over time in order to record change. It is a purely descriptive method. The airphotos may provide a high degree of detail but no provision is made for mapping or quantifying that information.

Airphoto disturbance mapping offers several advantages which airphoto monitoring does not include: 1) in examining the airphotos under magnification, far more detail can be seen and recorded than is available using the original scale of the photography; 2) in mapping areas of disturbed and undisturbed vegetation and open water, a permanent record of this information is created; and 3) in generalizing all disturbance into one category, a series of maps, more easily readable than airphotos, is created allowing the extent of disturbance or change to be seen at a glance.

## MONITORING VEGETATION CHANGE WITH AIRPHOTO AND GROUND SAMPLING DATA

In order to demonstrate change in vegetation with time, two techniques were used: airphoto grid assessment and airphoto interpreted vegetation mapping. These methods combine airphoto and ground sampling data.

### Airphoto Grid Assessment

Airphotos selected to cover the study site from 1972 to 77 (Table 14) were overlaid with a grid to scale. The percent of cell for each of several vegetation classes was determined. This information was summed for each vegetation class over each airphoto such that percent changes in the area of each class could be compared with time.

The selected imagery was viewed on a Richards light table. A grid size representing approximately 50 m on the ground was selected because it was best suited to the size of the vegetation patterns seen on a 3 October 1977 airphoto (originally at a scale of 1:11,500). This grid size was reduced to fit airphotos at scales of 1:19,100, 1:38,200, and 1:120,000 and a mylar overlay, showing the location of the transects and stations in the study area, also was made to fit each scale (Figure 31). Use of this transect-station overlay meant that ground sampling data observations could be used to help identify the vegetation patterns observed on each airphoto.

TABLE 14. LIST OF AIRPHOTOS USED IN AIRPHOTO GRID ASSESSMENT

| Date | Scale | CIR/Color |
|---|---|---|
| 4 June 1972 | 1:120,000 | CIR |
| 31 July 1974 | 1:120,000 | CIR |
| 25 September 1975 | 1:38,200 | CIR |
| 24 July 1975 | 1:38,200 | CIR |
| 24 September 1976 | 1:19,100 | CIR |
| 25 June 1977 | 1:38,200 | CIR |
| 25 June 1977 | 1:38,200 | Color |
| 3 October 1977 | 1:11,500 | CIR |

For each airphoto listed in Table 14, the percent of cell was recorded for each vegetation class present. Table 15 lists the vegetation classes which could be discerned on each photo.

A key was assembled for each airphoto describing the appearance of the different vegetation classes (Appendix F). These descriptions were obtained by identifying, on the airphoto, the locations where the vegetation classes appeared in the ground sampling data. The appearance of each vegetation class was defined in terms of color (tone) and texture. Many of the vegetation classes used in the airphoto grid assessment are the same as those used in the subjective classification of the ground sampling data.

Additional classes which could be identified by this method were Sedges and Grasses, Degraded Sedges and Grasses, *Typha latifolia, Scirpus fluviatilis*, Floating Mat, and *Lemna minor*. A Sedges and Grasses classification was used when *Carex lacustris* and *Carex stricta* could not be differentiated. In September 1975, the two *Carex* communities supported a dense *Calamagrostis canadensis* component. Once this species was greatly reduced in numbers, the *Carex stricta* and *Carex lacustris* classes were easier to separate. Dense clones of *Typha latifolia* and *Scirpus fluviatilis* were identifiable on airphotos at a scale of 1:28,200 or larger. Floating Mat refers to large areas where layers of the peat mat have separated from the wetland bottom and floated up to the surface. These areas of peat-mat are interspersed with the seedlings of densely clustered annuals. Together these two categories have a high reflectance. *Lemna minor* areas are easily

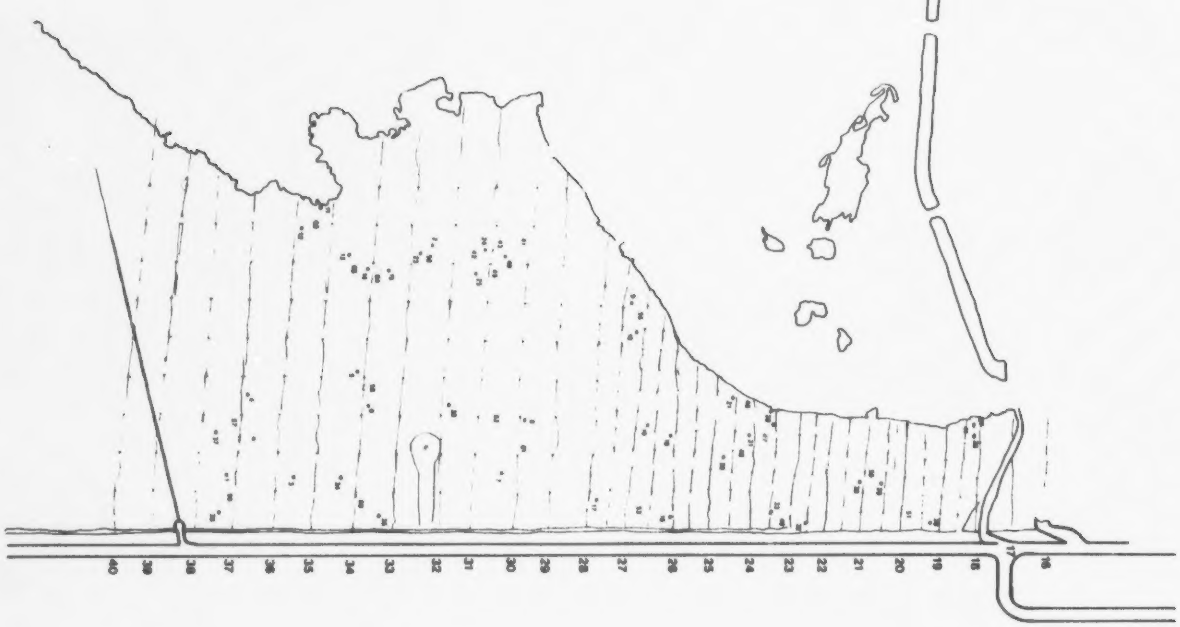

16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

Figure 31. Mylar overlay locating transects and sampling stations.

TABLE 15. VEGETATION CLASSES IDENTIFIED USING AIRPHOTO GRID ANALYSIS

| Vegetation classes | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1976 | 25 June 1977[a] | 25 June 1977[a] | 3 Oct. 1977 |
|---|---|---|---|---|---|---|---|---|
| *Carex lacustris* | | | X | X | X | X | X | X |
| Degraded *Carex lacustris* | | | | X | X | X | X | X |
| *Carex stricta* | | | X | X | X | X | X | X |
| Degraded *Carex stricta* | | | X | X | X | X | X | X |
| Sedges and grasses | X | X | | | | X | | X |
| Degraded sedges and grasses | | | | | | | | X |
| Transition | X | X | X | X | X | X | X | X |
| Degraded transition | | | | X | X | X | | |
| Emergents | X | X | X | X | X | X | X | X |
| Transition-emergents | | | | | | X | | |
| Disturbed emergents | | | | | | | | X |
| *Typha latifolia* | | | | X | X | X | X | X |
| *Scirpus fluviatilis* | | | X | | X | X | X | X |
| *Spiraea alba* | X | X | X | X | X | X | X | X |
| Shrubs | X | X | X | X | X | X | X | X |
| Weedy annuals | | | X | X | X | X | X | X |
| Floating mat | | | | | X | X | X | X |
| *Lemna minor* | | | | X | X | X | X | X |
| Open water | X | X | X | X | X | X | X | X |
| Shrub carr | X | X | X | X | X | X | X | X |
| Trees | X | X | X | X | X | X | X | X |

[a] Color film. Other photos are CIR.

identified by their high reflectance, distinctive color and flat, smooth texture.

Once data was recorded for all the cells considered on an airphoto, the percent of each vegetation class was determined for the entire scene by totaling the percent of each type of vegetation and dividing by the total number of cells times 100. This allowed changes in percent cover of the various vegetation classes to be compared with time.

Table 16 gives the percentages of each vegetation class for each of the airphotos analyzed. Not all classes could be identified on all dates of imagery due to differences of scale and data. In order to compare results from each airphoto, the 14 original vegetation classes were combined as follows. Shrubs, *Spiraea alba* and Open Water classes remained the same as previously. Transition and Emergents and *Typha latifolia* were combined into a Transition-Emergents category; *Carex stricta* and *Carex lacustris* were combined into a Sedges category; Degraded *Carex lacustris* and Degraded *Carex stricta* were combined into a Degraded Sedges class. The Other Disturbance class combined *Lemna minor*, Floating Mat, and Weedy Annuals. Degraded or disturbance classes did not appear on imagery taken prior to 1975. Table 17 gives the results of the grid analysis using these categories.

The percentage cover estimates of the different vegetation classes were more accurate using some airphotos than other methods. Vegetation features on the two high altitude photos (scale 1:120,000) were so small that neither vegetation classes nor total area covered could be identified accurately. The June 1977 color photo masked vegetation class differences and percent cover data are unreliable. The tones of the October 1977 airphoto highlighted disturbance (it appears greenish-purple) but made it difficult to distinguish different disturbance types. Consequently the analyst believes the vegetation class area estimates made from the color photos of September 1975, July 1976, September 1976 and June 1977 are the most representative of what appeared on the ground at that time. If approximately the same percentage cover estimate was made for a vegetation class from two photos dated consecutively, these two estimates are assumed to be correct.

Using airphoto grid assessment estimates, Shrubs made up approximately 7.0% of the area in the study site in 1972 and 1974 and continued to do so in 1977. Open Water areas consisted of only 2.0% of the area in 1972 and 1974 but increased to 10% in 1977. Open Water area is much greater (33%) if Floating Mat and *Lemna minor* areas also are included. From Table 17 it would appear that the amount of Open Water was overestimated in the July 1976 color infrared photo and underestimated in the June 1977 color photo. On the July 1976 airphoto, areas with much interspersion are a very dark green and may have been recorded in some instances as Open Water. On the June 1977 color image, the color of the water in the study site is brownish-green and difficult to distinguish from some of the vegetation.

The Transition and Emergents classes were difficult to distinguish, so they were combined for purposes of this analysis. The Transition class often was difficult to distinguish from the Floating Mat class. As a

TABLE 16. CLASSES ORIGINALLY USED TO SUM GRID ANALYSIS DATA

| Vegetation classes | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1976 | 25 June 1977[a] | 25 June 1977[a] | 3 Oct 1977 |
|---|---|---|---|---|---|---|---|---|
| Shrub | 6.8 | 4.6 | 7.4 | 6.8 | 5.9 | 6.0 | 5.3 | 7.8 |
| Open | 2.1 | 2.2 | 5.2 | 9.5 | 7.6 | 7.4 | 5.5 | 10 |
| *Typha latifolia* | - | - | - | - | 1.4 | 5.8 | 0.5 | 1.9 |
| Transition | 25 | 15 | 16 | 13 | 10 | 12 | - | - |
| Emergent | 9.3 | 3.3 | 9.6 | 18 | 9.8 | 15 | 24 | 24 |
| Sedges | 50 | 75 | - | - | - | - | 23 | 5.0 |
| Degraded sedges | - | - | - | - | - | 0.5 | 5.2 | 3.6 |
| *Carex stricta* | - | - | 31 | 20 | 23 | 17 | - | 6.1 |
| Degraded *Carex stricta* | - | - | - | 3.3 | 10 | 13 | 6.8 | 8.5 |
| *Carex lacustris* | - | - | 19 | 6.4 | 5.9 | 1.9 | - | - |
| Degraded *Carex lacustris* | - | - | - | 6.5 | 7.8 | 11 | 8.9 | - |
| *Spiraea alba* | 6.5 | a | 9.5 | 8.2 | 9.4 | 5.7 | 8.5 | 9.2 |
| *Lemna minor* | - | - | 2.2 | 7.1 | 8.1 | 4.4 | 3.6 | 21 |
| Floating mat | - | - | - | - | - | - | 8.7 | 1.6 |
| Weedy Annuals | - | - | - | 1.3 | 0.2 | 7.0 | - | 1.1 |

[a] Not distinguishable on this image.

TABLE 17. GRID ANALYSIS PERCENT COVER DATA

| Vegetation classes | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1976 | 25 June 1977a | 25 June 1977a | 3 Oct. 1977 |
|---|---|---|---|---|---|---|---|---|
| Shrub | 6.8 | 4.6 | 7.4 | 6.8 | 5.9 | 6.0 | 5.3 | 7.8 |
| *Spiraea* | 6.5 | - | 9.5 | 8.2 | 9.4 | 5.7 | 8.5 | 9.2 |
| Open | 2.1 | 2.2 | 5.2 | 9.5 | 7.6 | 7.5 | 5.5 | 10 |
| Transition-Emergents | 35 | 19 | 25 | 30 | 21 | 33 | 24 | 25 |
| Sedges | 50 | 75 | 50 | 27 | 29 | 19 | 25 | 11 |
| Degraded Sedges | - | - | - | 9.7 | 18 | 24 | 21 | 12 |
| Other Disturbance | - | - | 2.2 | 8.4 | 8.3 | 11 | 12 | 24 |

result, the percentage cover for this category varies. The Transition-Emergents class was particularly difficult to distinguish on high-altitude imagery where little detail is visible.

As water depths increased by 10 cm in the wetland, the growth of the Transiton and Emergents species was encouraged. This was countered by the fact that the areas of Open Water were increasing at the expense of the Transition class. While Emergents species were increasing, Transition species were decreasing so that total Transition-Emergents remained approximately the same over 4 yr.

Sedges cover was estimated at 50% on the September 1972 and September 1975 airphotos. The most rapid destruction at the study site took place from 1975 to 1976. During this time the Sedges class cover decreased from 50% to 25 to 30%. The June 1977 color infrared photo shows Sedges cover being further reduced to 19%. Sedges were difficult to identify on the October 1977 airphoto which explains their very low (11%) cover estimate.

As Sedges decreased by 39% from 1974 to 1977, Degraded Sedges increased from 0 to 24%. The estimate of Degraded Sedges dropped low on the October 1977 photo where they could not be distinguished from the Other Disturbance class. Other Disturbance increased from 2.2% in September 1975 to 11 to 12% in June 1977. Eight percent of the site was classified *Spiraea alba* throughout the span of the study.

Total Open Water, Disturbed Sedges, and Other Disturbance increased from 2.5% in 1972 to 46% in 1977. This seems to be an accurate approximation, based on ground knowledge.

Table 18 lists results of the chi square tests done with grid analysis results from a number of dates. Chi square tests done comparing data collected in 1975 and later were significant at the 0.01 or 0.001 level. In order to meet the requirements of the test, some of the vegetation categories listed in Table 16 had to be combined. Vegetation categories used for these tests were Sedges, Degraded Sedges, Transition-Emergents, Spiraea, Shrubs, and Other Disturbance which included the Open Water category.

TABLE 18. CHI SQUARE TESTS ON GRID ANALYSIS DATA

| Grid analysis dates | Not significant | 0.01 | 0.001 |
|---|---|---|---|
| June 1972 and September 1975 | X | | |
| June 1972 and July 1976 | | X | |
| September 1975 and June 1977 | | | X |
| June 1972 and June 1977 | | | X |

## Airphoto Interpreted Vegetation Maps

Vegetation classification maps were drawn in the same manner as the disturbance maps. The original photo was enlarged 6.67 times and projected on a ground glass screen. This enlarged image was overlaid with a mylar sheet (to scale) showing the location of transects 18 to 42 and the sampling along each of these transects. Ground sampling data for each station which had been printed out by computer and subjectively classified for all stations served as the basis for identifying vegetation classes on the mylar. The data based on ground sampling could be located specifically at the sampling points shown on the magnified images of the photos. The patterns seen on the photo images then could be labeled. The vegetation classes were first delineated on the mylar with pencil, then redrawn in ink and labeled. Each map was enlarged or reduced as necessary to bring all the maps to a common scale.

When the maps were brought to a common scale, each was covered with a sheet of graph paper. Total study site area and the area of each vegetation class were determined for each map. The total area of each vegetation class was divided by the total site area and multiplied by 100 to provide the relative percentages for each class. Table 19 lists the eight photos used to generate the airphoto interpreted vegetation maps.

TABLE 19. LIST OF AIRPHOTOS USED TO GENERATE AIRPHOTO INTERPRETED VEGETATION MAPS

| Date | Scale | Color/CIR |
|---|---|---|
| 4 June 1972 | 1:120,000 | CIR |
| 31 July 1974 | 1:120,000 | CIR |
| 25 September 1975 | 1:38,200 | CIR |
| 24 July 1976 | 1:38,200 | CIR |
| 24 September 1976 | 1:19,100 | CIR |
| 25 June 1977 | 1:38,200 | CIR |
| 25 June 1977 | 1:38,200 | Color |
| 3 October 1977 | 1:11,500 | CIR |

A color and texture key was assembled for each airphoto, to facilitate consistent mapping of the various communities (Appendix G). Sixteen vegetation classes were identified using color infrared airphotos taken 25 September 1975 and 25 June 1977. Although one less class was identified on the 25 June 1977 color airphoto and the 3 October 1977 airphoto, the analyst felt less confident about vegetation class identification using these photos. Table 20 lists the vegetation classes discernible on each of the airphoto interpreted maps.

TABLE 20. VEGETATION CLASSES DISCERNIBLE ON PHOTO INTERPRETED VEGETATION MAPS

| Vegetation classes | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1976 | 25 June 1977 | 25 June 1977 | 3 Oct 1977 |
|---|---|---|---|---|---|---|---|---|
| A. *Carex lacustris* | | | X | X | X | X | X | X |
| B. Disturbed *Carex lacustris* | | | | X | X | X | X | X |
| C. *Carex stricta* | | | X | X | X | X | X | X |
| D. Disturbed *Carex stricta* | | | X | X | X | X | X | X |
| E. Sedges and Grasses | X | X | | | | | | |
| F. Transition | X | X | X | X | X | X | X | X |
| G. Disturbed Transition | | | | X | X | X | | |
| H. Emergents | X | X | X | X | X | X | X | X |
| I. Disturbed Emergents | | | | | | | | X |
| J. *Typha latifolia* | | | | X | X | X | X | |
| K. *Scirpus fluviatilis* | | | X | | X | X | X | X |
| L. *Spiraea alba* | X | X | X | X | X | X | X | X |
| M. Shrubs | X | X | X | X | X | X | X | X |
| N. Weedy Annuals | | | X | X | X | X | X | X |
| O. Floating Mat | | | | | X | X | X | X |
| P. *Lemna minor* | | | X | X | X | X | X | X |
| Q. Open Water | X | X | X | X | X | X | X | X |
| R. Shrub carr | X | X | X | X | X | X | X | X |
| S. Trees | X | X | X | X | X | X | X | X |

Table 21 classifies the vegetation classes according to how easy they were to identify: easy, moderately difficult, difficult, and very difficult.

TABLE 21. EASE WITH WHICH VEGETATION CLASSES COULD BE IDENTIFIED ON AIRPHOTOS

| Easy | Moderately Easy | Difficult | Very Difficult |
|---|---|---|---|
| Sedges and Grasses | *Carex lacustris* | Transition | Degraded Emergents |
| Degraded Sedges | *Carex stricta* | Emergents | |
| Shrubs | *Typha latifolia* | Floating Mat | |
| *Lemna minor* | *Scirpus fluviatilis* | Weedy Annuals | |
| Open Water | *Spiraea alba* | Degraded *Carex lacustris* | |
| Shrub carr | | Degraded *Carex stricta* | |
| Trees | | | |

Sedges and Grasses and Degraded Sedges were easy to identify. It was slightly more difficult to distinguish *Carex lacustris* from Degraded *Carex stricta*. The Shrubs, Trees and Shrub carr classes were all easy to identify due to their coarse textures and generally rounded crown shapes. Open Water was easily identifiable on all color infrared imagery. *Lemna minor*, with its bright reflectance and flat texture, could be identified easily.

*Typha latifolia* and *Scirpus fluviatilis*, occurring in dense patches, were moderately easy to identify due to their distinctive clone growing patterns and coarse textures. *Spiraea alba* was easy to recognize when it occurred in dense patches, but difficult to identify when interspersed with dense *Carex stricta* and *Calamagrostis canadensis*.

The Transition and Emergents classes were always difficult to distinguish due to their similarity of color and texture. The same was true of the Floating Mat and Weedy Annuals classes.

Table 22 lists all the vegetation classes identified on the eight airphoto interpreted maps and gives the relative percentage of each class per airphoto. Differences of scale and date prevented identification of all classes on all dates of imagery. Consequently classes were combined as follows: The Shrubs, *Spiraea*, and Open Water classes remained unchanged. The Transition, Emergents, *Typha* and *Scirpus* classes were combined into a Transition-Emergents category. *Carex lacustris* and *Carex stricta* were combined into a Sedges class. Degraded *Carex lacustris* and Degraded *Carex stricta* were combined into a Degraded Sedges class. The Other Disturbance

TABLE 22. RELATIVE PERCENTAGE COVER OF EACH VEGETATION CLASS DEFINED USING AIRPHOTO INTERPRETED VEGETATION MAPPING

| Vegetation classes | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1976 | 25 June 1977 | 25 June 1977 | 3 Oct 1977 |
|---|---|---|---|---|---|---|---|---|
| A. *Carex lacustris* | | | 23 | 5.3 | 5.9 | 7.2 | 9.4 | 7.0 |
| B. Degraded *Carex lacustris* | | | | 7.6 | 9 | 11 | 10 | 8.9 |
| C. *Carex stricta* | | | 22 | 30 | 22 | 18 | 5.5 | 15 |
| D. Degraded *Carex stricta* | | | 1.1 | 10 | 5.9 | 11 | 13 | 11 |
| E. Sedges and Grasses | 24 | 30 | | | | | | |
| F. Transition | 17 | 10 | 12 | 1.8 | 12 | 4.2 | 12 | 4.9 |
| G. Degraded Transition | | | 1.5 | 5.3 | 1.4 | 7.2 | | |
| H. Emergents | 10 | 9.9 | 7.6 | 16 | 16 | 9.7 | 12 | 9.5 |
| I. Degraded Emergents | | | | | | | | 2.0 |
| J. *Typha latifolia* | | | | 0.5 | 1.6 | 0.6 | 0.3 | 0.5 |
| K. *Scirpus fluviatilia* | | | 1.8 | 0.5 | 0.5 | 0.7 | 0.3 | 0.5 |
| L. *Spiraea alba* | 10 | 11 | 11 | 11 | 4.2 | 7.6 | 11 | 7.5 |
| M. Shrubs | 2.7 | 4.3 | 9.2 | 2.4 | 4.0 | 2.7 | 2.1 | 4.6 |
| O. Weedy Annuals | | | 3.1 | 2.1 | 3.4 | 3.6 | 1.1 | 3.5 |
| P. Floating Mat | | | | 1.1 | 2.0 | 5.1 | 11 | 9.2 |
| Q. *Lemna minor* | | | 1.8 | 2.3 | 4.7 | 2.2 | 2.5 | 2.9 |
| R. Open Water | 0.2 | | 1.5 | 1.6 | 2.2 | 5.8 | 4.8 | 10 |
| S. Shrub carr[a] | | | | | | | | |
| T. Trees | 0.8 | | 1.6 | 1.3 | 1.9 | 1.7 | 1.7 | 1.1 |

[a] Appears at far southern end of marsh sedge meadow outside the study site.

combined all the Degraded classes not already classified, as well as *Lemna minor*, Floating Mat and Weedy Annuals (Table 23).

Results of the airphoto interpreted vegetation mapping show that Shrubs probably made up 5.0 to 6.0% of the area within the study site while *Spiraea* accounted for 10% of the area. These figures remained fairly constant over 3 yr. This method shows Open Water increasing from 0.2% in 1974 to 10% in 1977. The analyst believes Open Water was generally underestimated since it often appeared as rivulets among the vegetation, making it difficult to accurately estimate its relative cover. The Transition-Emergents class decreased from 20 to 25% of the total area in 1974 to 1975 to approximately 15% by 1977 while Sedges decreased from 45% to 22% of the total area over the same period. Percentage area of Sedges was underestimated on the 1:120,000 scale airphotos (4 June 1972 and 31 July 1974). At this scale, features often were so small that lines could not be drawn around them and consequently much of the area remained unclassified.

The Degraded Sedges class increased in area from 0 to 22% between 1974 to 1975 and 1977. The Other Disturbance class increased from 0 in 1974 to 16 to 18% of the total area in 1977. Total disturbed area (combining Open Water, Degraded Sedges, and Other Disturbance) increased from 0.2% in 1972 to 37% in 1977. Percent unclassified area, discounting the 1:120,000 airphotos, varied from 1.3 to 3%.

### Changes Observed on the Photo Interpreted Vegetation Maps--

On the 4 June 1972 map (Figure 32) interpreted from a high altitude color infrared airphoto, scale 1:120,000, two discrete ponds of open water are visible. Otherwise the vegetation is a continuous mat of sedges and grasses, transition and emergent vegetation, shrubs and *Spiraea* (Table 20).

The 31 July 1974 map (Figure 33) was interpreted from another high altitude color infrared 1:120,000 scale airphoto. Far less detail of color and texture were available on this airphoto. Consequently no open water could be seen and vegetation classes could not be identified with the same level of confidence as the 4 June 1972 airphoto.

The map drawn from the 25 September 1975 color infrared airphoto, scale 1:38,200, shows far more detail (Figure 34). Thirteen vegetation classes could be identified using this airphoto in contrast with only five to eight classes identified on the high altitude imagery. The two open ponds visible on the 4 June 1972 airphoto can be seen on this airphoto. In addition a channel can be seen running along the far west side of the study area. Disturbance is apparent in two woody areas; one located near the keyhole well, the other near the northern end of the study site where a road was relocated. Another indicator of disturbance, duckweed, which floats on still, open water can be seen along the north knoll and in the western portion of the study site along the lowland forest. Figure 35 was made from an airphoto taken approximately 7 months after the cooling lake was filled and 4 months after Unit I went on-line.

## TABLE 23. VEGETATION CLASSES USED TO SUMMARIZE AIRPHOTO INTERPRETED VEGETATION MAPS

| Vegetation classes | Relative % of each class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4 June 1972 | 31 July 1974 | 25 Sept. 1975 | 24 July 1976 | 24 Sept. 1977a | 25 June 1977a | 25 June 1977a | 3 Oct. 1977 |
| Shrub | 8.7 | 4.3 | 11 | 3.7 | 5.9 | 4.6 | 3.8 | 5.7 |
| *Spiraea* | 5.2 | 11 | 11 | 11 | 4.2 | 7.6 | 11 | 7.5 |
| Open Water | 0.2 | - | 1.5 | 1.6 | 2.2 | 5.8 | 4.8 | 10 |
| Transition-Emergents | 27 | 20 | 22 | 19 | 31 | 14 | 25 | 15 |
| Sedges | 24 | 30 | 45 | 35 | 27 | 25 | 15 | 22 |
| Degraded Sedges | - | 1.1 | - | 18 | 15 | 22 | 23 | 20 |
| Other Disturbance | - | - | 7.5 | 11 | 11 | 18 | 15 | 17 |
| Unclassified | 35 | 35 | 1.9 | 1.3 | 3.0 | 1.8 | 2.1 | 1.3 |

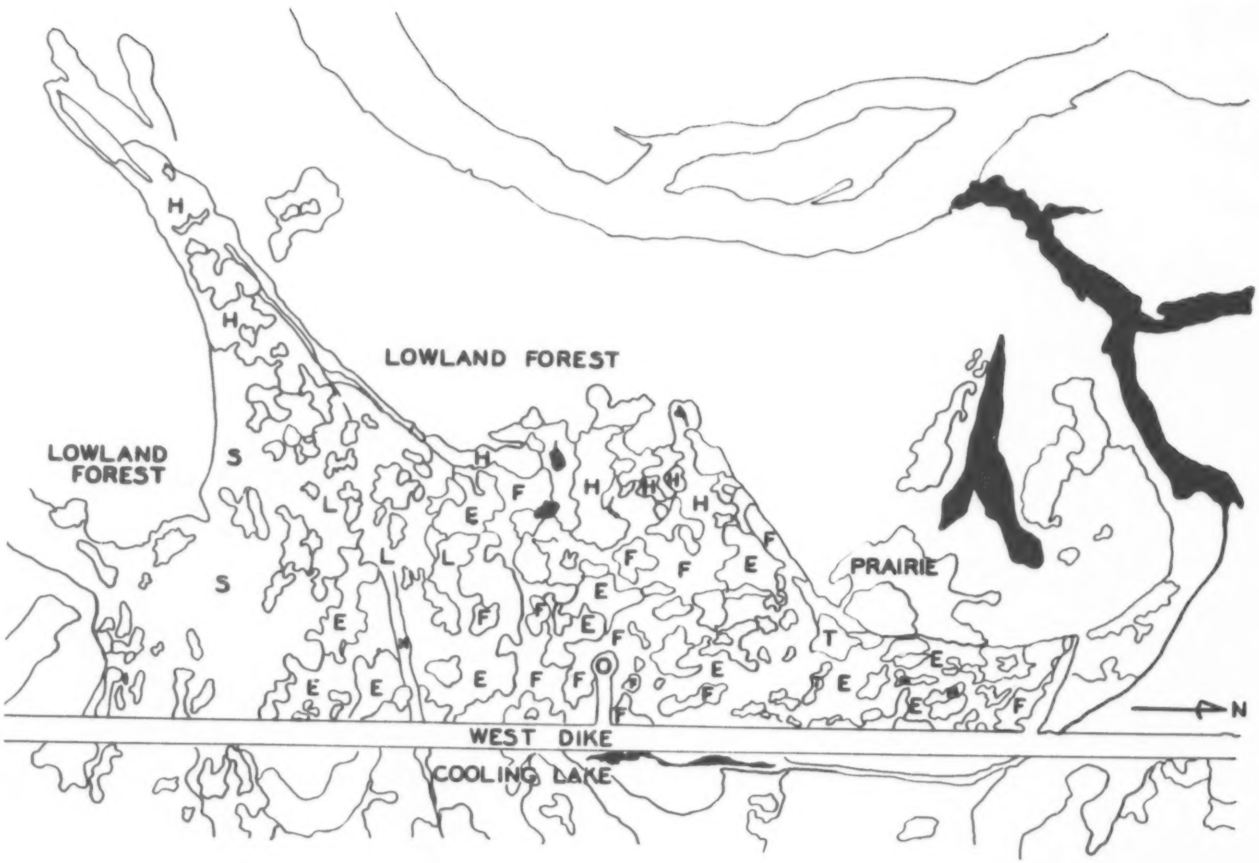

LOWLAND FOREST
LOWLAND FOREST
PRAIRIE
WEST DIKE
COOLING LAKE
N

Figure 32. Photo interpreted vegetation map on June 4, 1972.

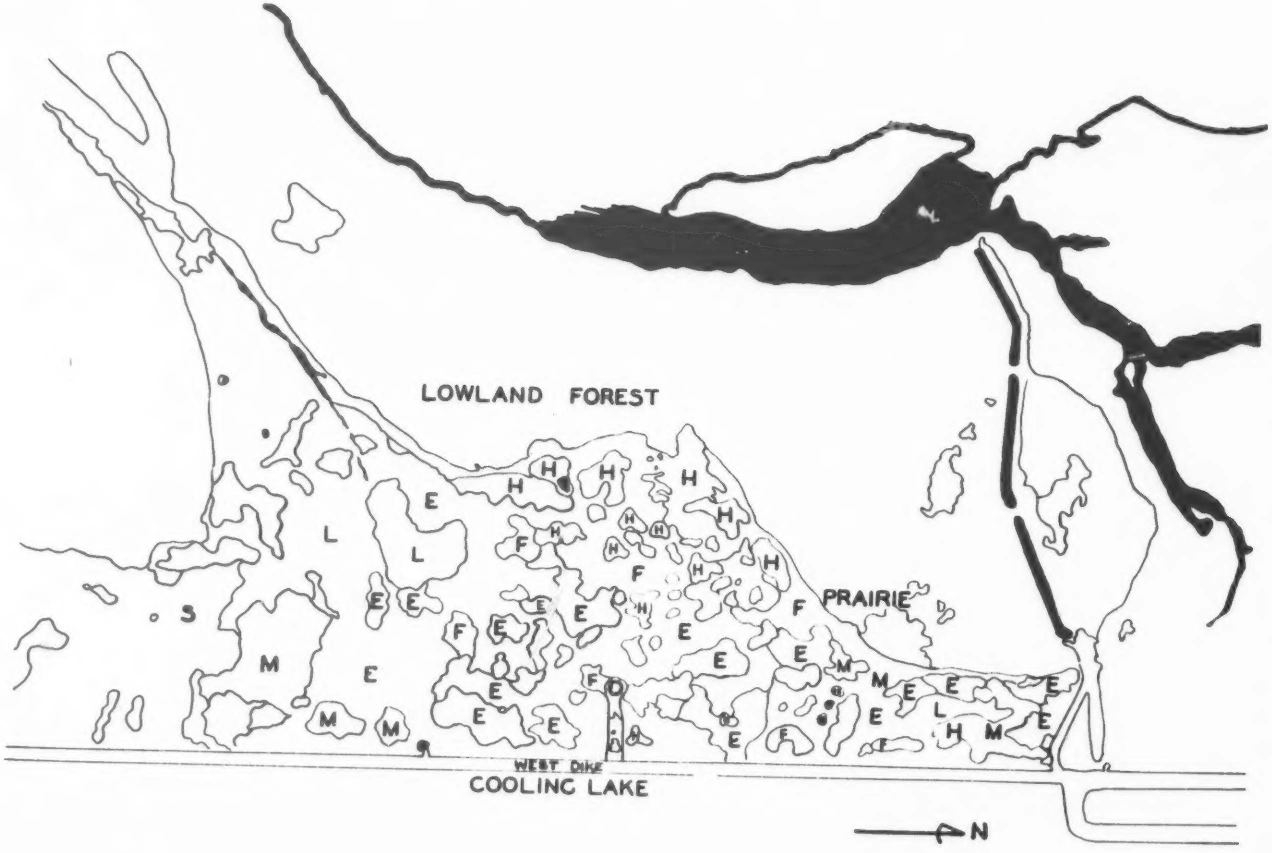

LOWLAND FOREST
PRAIRIE
WEST DIKE
COOLING LAKE
N

Figure 33. Photo interpreted vegetation map in July 31, 1974.

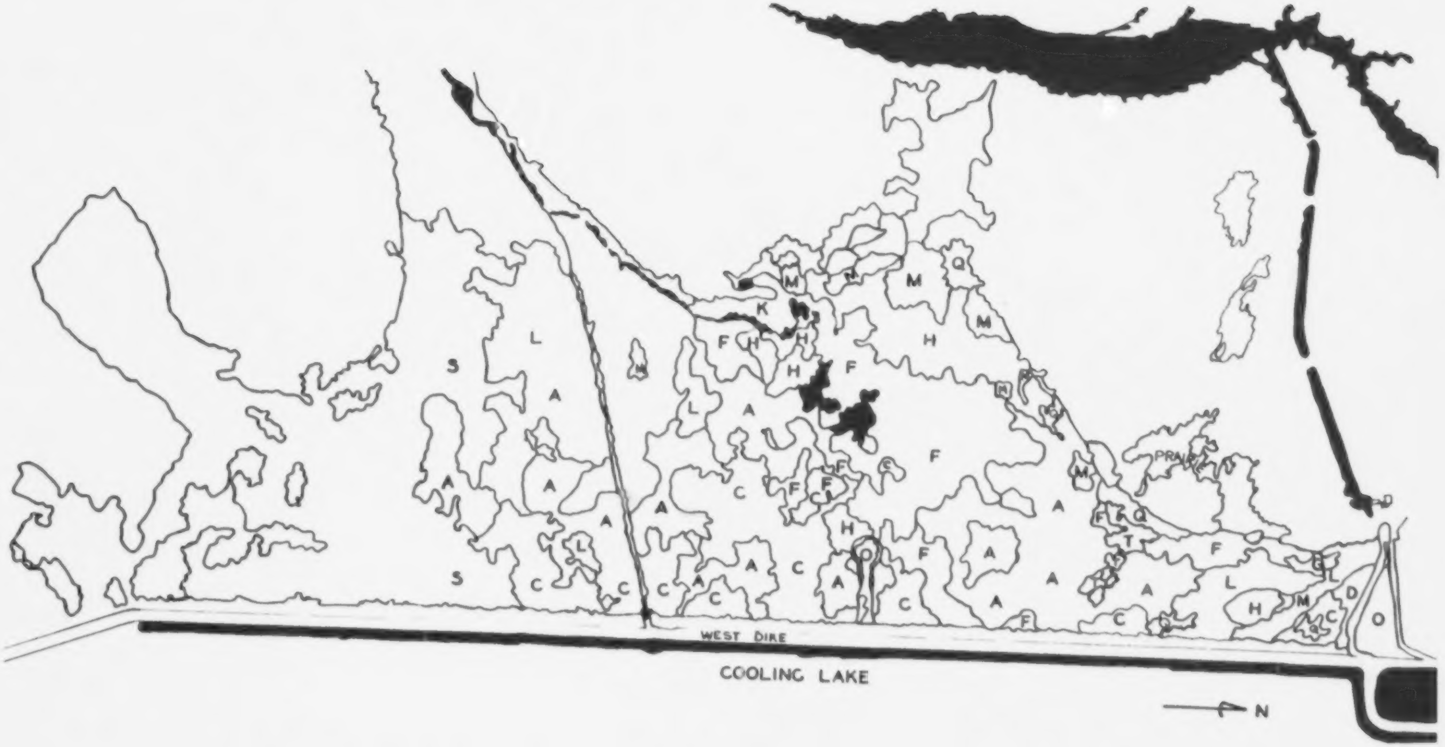

WEST DIKE
COOLING LAKE
N

Figure 34. Photo interpreted vegetation map on September 25, 1975.

The 24 July 1976 map (Figure 35), drawn from a color infrared airphoto, scale 1:38,200, shows that nearly 1 yr later, open water is appearing in the north end of the marsh/sedge meadow along with weedy annuals and *Lemna minor*. *Lemna minor* is also becoming prominent in the center of the wetland. Large areas of Degraded *Carex lacustris* and *Carex stricta* are appearing along the dike.

Figure 36 was drawn from a 24 September 1976 color infrared airphoto, scale 1:19,100. The larger scale provides more detail. This map does not show much change from Figure 23 except that there is more open water visible where there was *Lemna minor* previously, indicating continued peat mat erosion. And on this airphoto, more area in the center of the study site could be classified as floating mat. This may be a function of the vegetation's partial dieback, making mud areas more visible.

Figure 37 is a map drawn from a 25 June 1977 color infrared airphoto, original scale 1:38,200. Channels are now seen extending from the northern end of the study site through the tree island and into the central portion of the study site, finally joining Duck Creek. Figure 38, drawn from a 25 June 1977 color airphoto, original scale 1:38,200, shows far more open water than was visible during the summer and fall of 1976. Open water now appears to be peppered throughout the study site. The central portion of the study area appears to be floating mat.

The 3 October 1977 map (Figure 39) was drawn from a color infrared airphoto, original scale 1:11,500. This scale offered so much subtle color and texture information that it was difficult to generalize vegetation patterns. Disturbance is highlighted in pink tones on this airphoto but it is difficult to differentiate the different types of disturbance. The area of floating mat has increased to cover the entire central portion of the study site.

In order to photo-interpret maps showing this degree of detail it is necessary to collect extensive ground sampling data, including species stem counts, since numbers of individual species as well as the identification of species present is important.

Ideally the photo interpretation of airphotos should be done on an orthophoto base map. This would remove any effects of tilt and also any changes of scale on the airphoto due to differences in terrain relief. Relief at the study site was negligible but airphotos did suffer from a slight element of tilt.

## Comparing Airphoto Grid Analysis and Airphoto Interpreted Mapping Results

Airphoto grid analysis and airphoto interpreted vegetation mapping detected change in vegetation community area and location over 3 yr. Using each method, a definite trend from healthy marsh/sedge meadow vegetation to heavily eroded and disturbed wetland vegetation was observed. Airphoto grid analysis and airphoto interpreted vegetation mapping demonstrated changes in

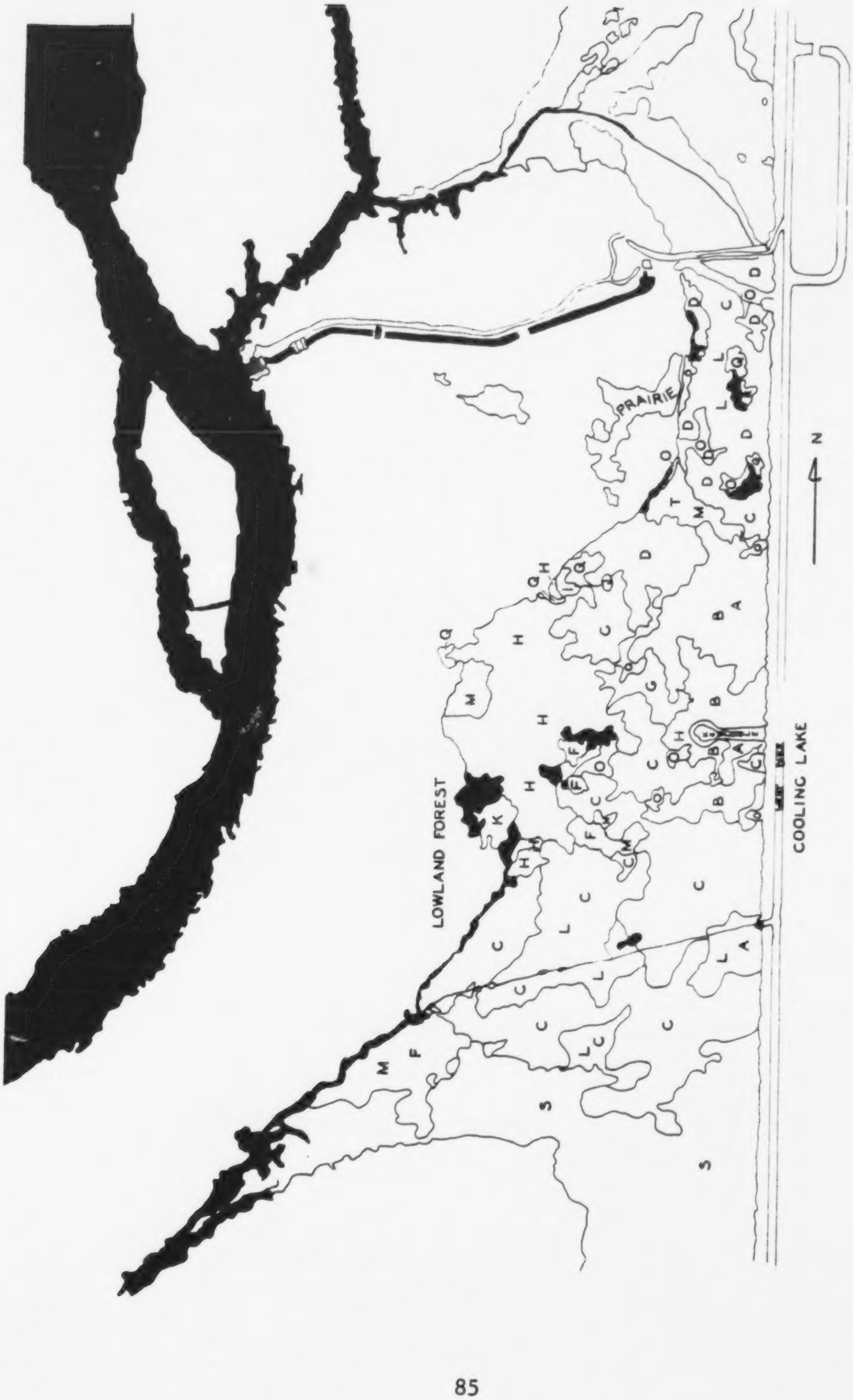

LOWLAND FOREST
PRAIRIE
COOLING LAKE
N

Figure 35. Photo interpreted vegetation map on July 24, 1976.

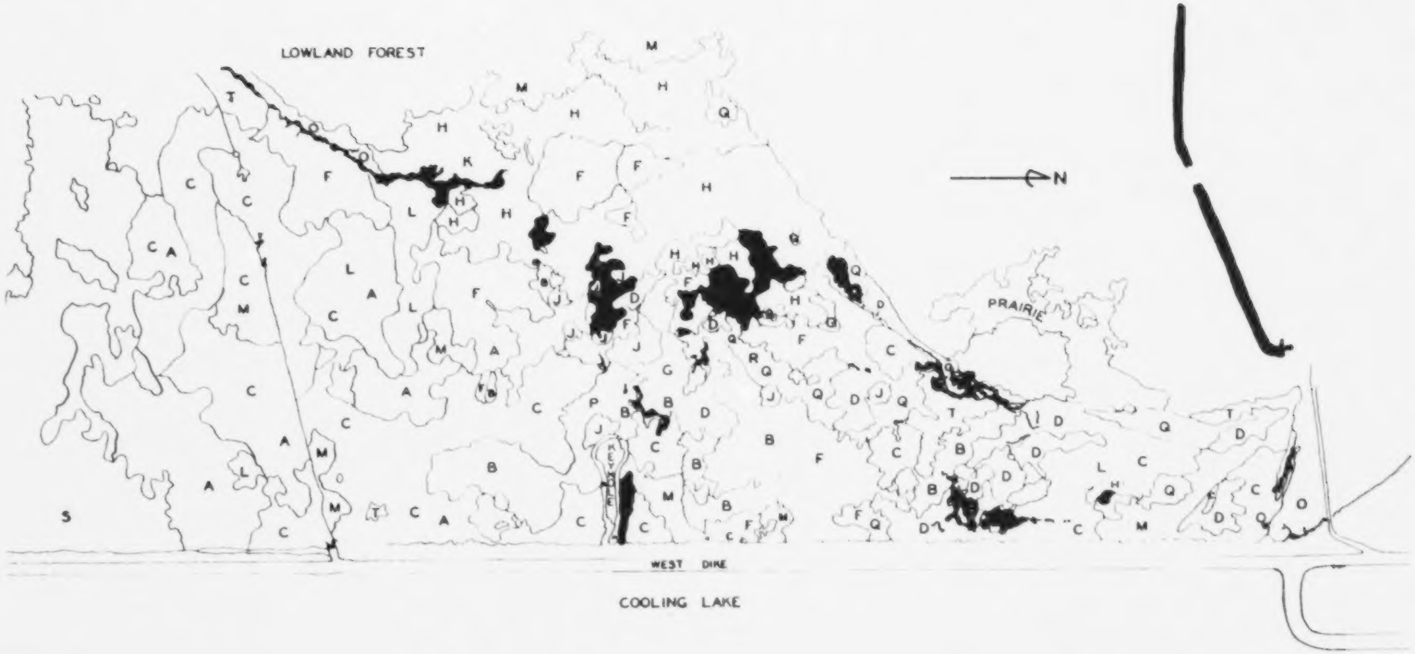

LOWLAND FOREST
PRAIRIE
N
WEST DIKE
COOLING LAKE

Figure 36. Photo interpreted vegetation map in September 24, 1976.

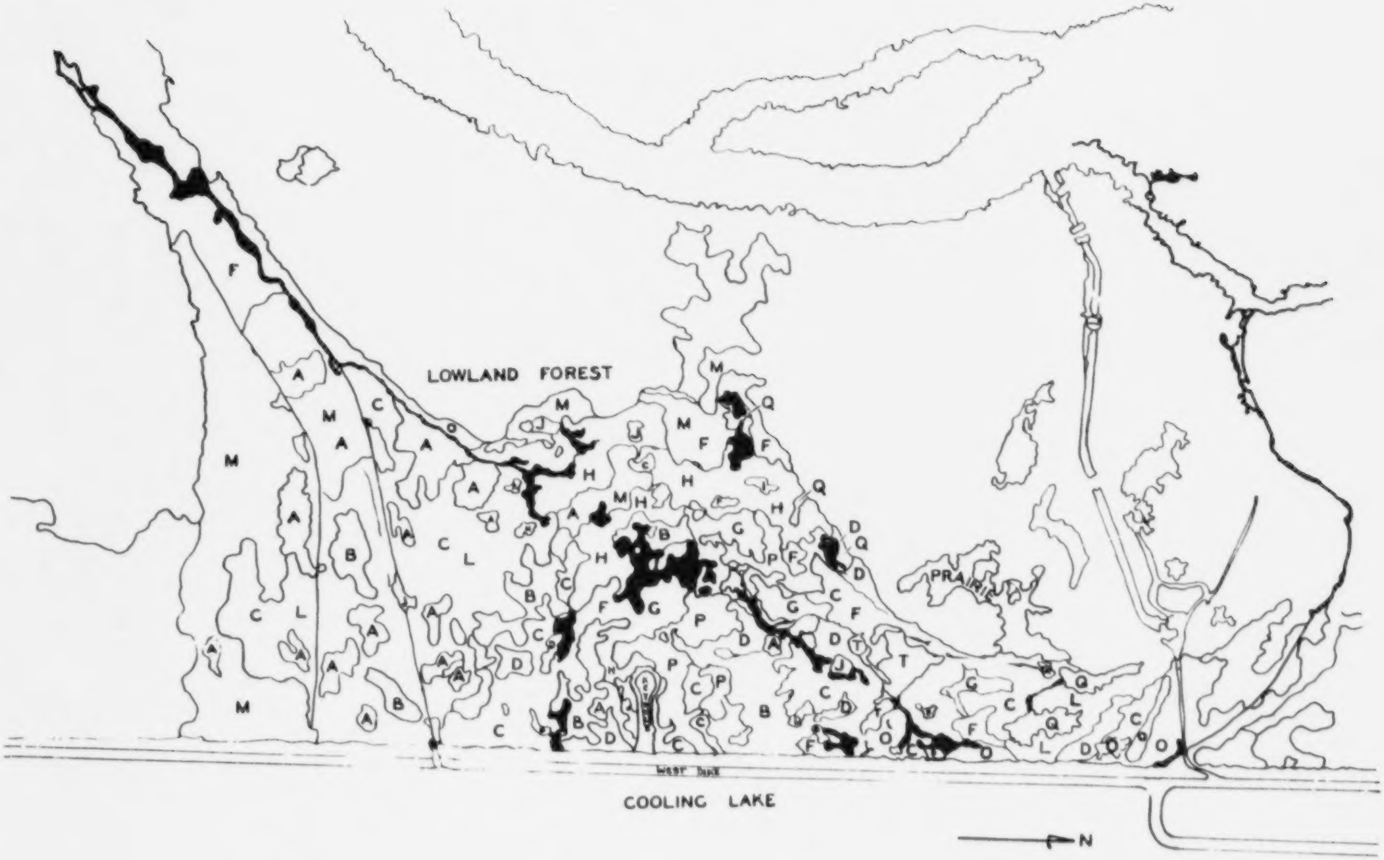

LOWLAND FOREST
PRAIRIE
WEST DIKE
COOLING LAKE
N

Figure 37. Photo interpreted vegetation map on June 25, 1977.

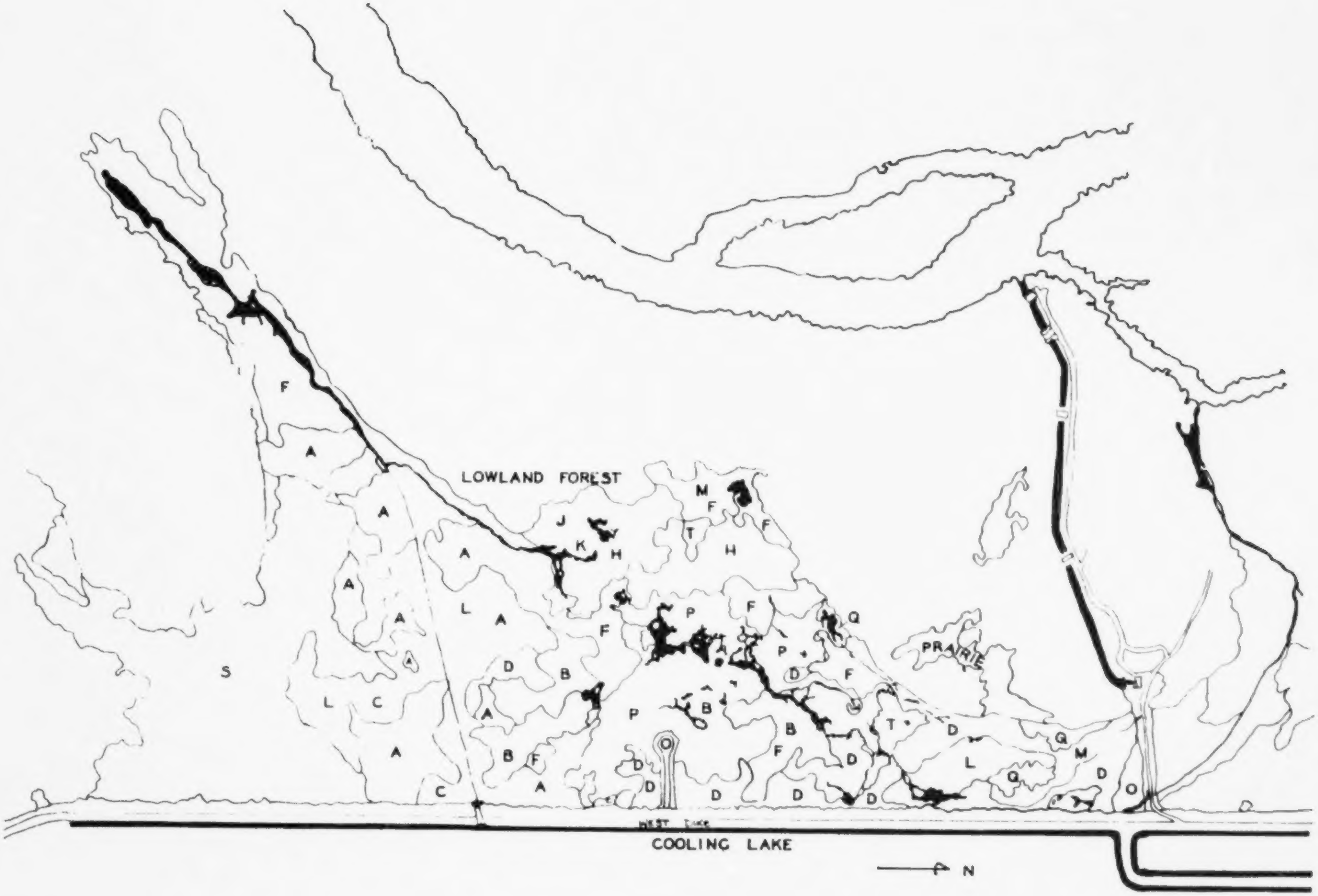

F
A
LOWLAND FOREST
M
F
A
J
K
H
T
H
F
A
A
L
A
A
P
F
Q
F
P
PRAIRIE
S
A
D
B
D
F
L
C
P
B
A
T
D
B
Q
M
F
D
A
B
F
D
L
Q
D
C
A
D
D
D
D
O
WEST LAKE
COOLING LAKE
N

Figure 38. Photo interpreted vegetation map on June 15, 1977.

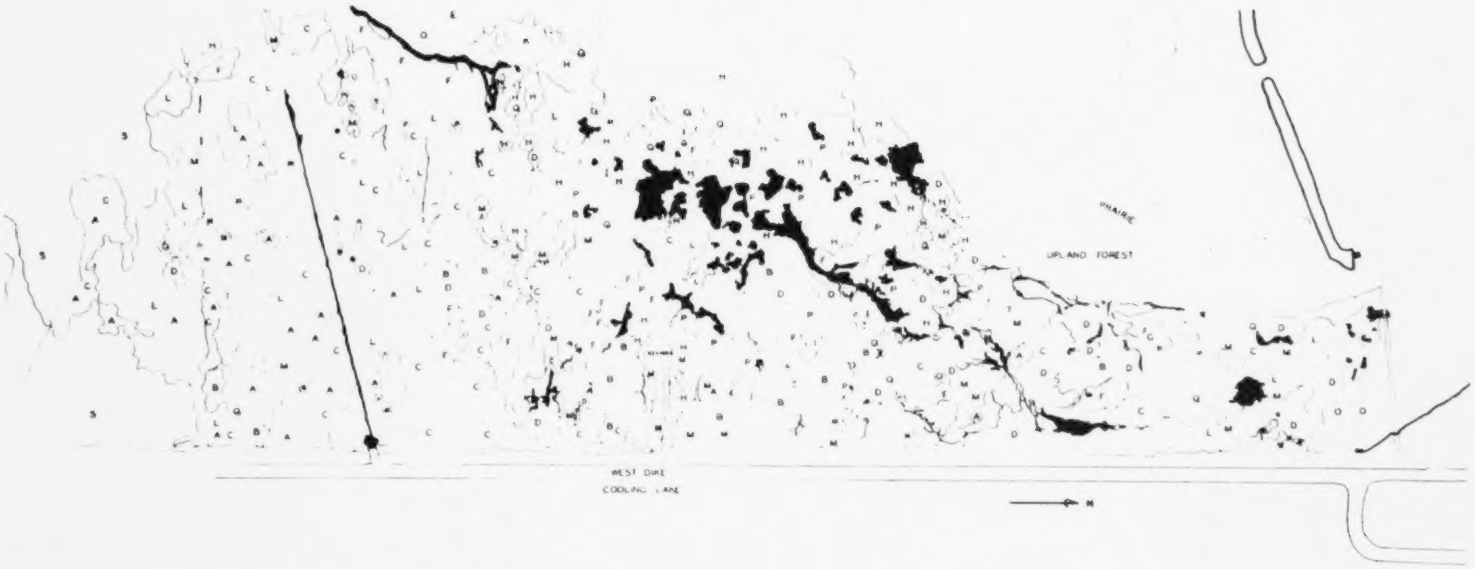

PRAIRIE
UPLAND FOREST
WEST DIKE
COOLING LAKE
N

Figure 39. Photo interpreted vegetation map on October 3, 1977.

the area of a few, large clone-forming species. General comments about each method and a comparison of their results follow.

The estimation of percent cover of vegetation classes within a grid cell was the strength and weakness of the airphoto grid analysis method. Another weakness was the procedure of viewing one cell at a time with little reference to what was around it through a 15 power microscope. At the same time, however, cell by cell viewing allowed a more precise percent estimate of vegetation classes than was possible using airphoto interpreted vegetation mapping.

Airphoto interpreted mapping necessitated drawing lines around vegetation classes. Because the *Carex lacustris* and *Carex stricta* communities and the Transition and Emergents communities tended to grade into one another, drawing a line around a community could not always be done with confidence. The technique of placing a grid over a finished map and counting numbers of cells of each cover type resulted in area estimates that were less consistent than those done with grid analysis. Although two partial cells of a vegetation class were counted as one cell, the percent cover of all vegetation classes was consistently underestimated.

Table 24 lists summary vegetation classes and percent cover results, airphoto by airphoto, using airphoto grid analysis and airphoto interpreted vegetation mapping. Poor agreement was found between the two methods. When the seven vegetation classes of Table 24 are combined in Table 25 and expressed as Disturbed and Undisturbed Vegetation and Open Water, agreement among methods is close.

Airphoto grid analysis and airphoto interpreted vegetation mapping both define many vegetation classes and quantify the percent cover of each class. Beyond these similarities are differences: with airphoto grid analysis, percent cover determination is done simultaneously with vegetation class definition on a cell-by-cell basis whereas with airphoto interpreted vegetation mapping, the analyst maps the entire scene and then lays a grid over it to determine the total area mapped and the percent total area made up by each vegetation class.

The analyst believes airphoto interpreted vegetation mapping is the less accurate of the two methods because it uses a technique to determine percent vegetation class cover which is crude in comparison to the technique used to determine cover in airphoto grid analysis. (This does not have to be the case. Mapped areas could be digitized to obtain accurate cover determinations from airphoto interpreted vegetation maps (Niemann 1979).) This method offers the advantage of generating photo interpreted vegetation maps. The slightly greater time and dollar costs associated with airphoto interpreted vegetation mapping result from the drafting which is necessary to produce finished maps.

TABLE 24. COMPARISON OF PERCENT COVER RESULTS USING AIRPHOTO GRID ANALYSIS AND AIRPHOTO INTERPRETED VEGETATION MAPPING

| | Grid analysis | Vegetation mapping | | Grid analysis | Vegetation mapping |
|---|---|---|---|---|---|
| June 4, 1972 | | | July 31, 1974 | | |
| Shrubs | 6.8 | 8.7 | Shrubs | 4.6 | 4.3 |
| *Spiraea* | 6.5 | 5.2 | *Spiraea* | - | 11 |
| Open Water | 2.1 | 0.2 | Open Water | 2.2 | - |
| Transition-Emergents | 35 | 27 | Transition-Emergents | 19 | 20 |
| Sedges | 50 | 24 | Sedges | 75 | 30 |
| Degraded Sedges | - | - | Degraded Sedges | - | - |
| Other Disturbance | - | 2.5 | Other Disturbance | - | - |
| Unclassified | - | 35 | Unclassified | - | 35 |
| September 25, 1975 | | | July 24, 1976 | | |
| Shrubs | 7.4 | 11 | Shrubs | 6.8 | 3.7 |
| *Spiraea* | 9.5 | 11 | *Spiraea* | 8.2 | 11 |
| Open Water | 5.2 | 1.5 | Open Water | 9.5 | 1.6 |
| Transition-Emergents | 25 | 22 | Transition-Emergents | 30 | 19 |
| Sedges | 50 | 45 | Sedges | 27 | 35 |
| Degraded Sedges | - | - | Degraded Sedges | 9.7 | 18 |
| Other Disturbance | 2.2 | 7.5 | Other Disturbance | 8.4 | 11 |
| Unclassified | - | 1.9 | Unclassified | - | 1.3 |
| Dike | - | - | Dike | - | - |
| September 24, 1976 | | | June 25, 1977 | | |
| Shrubs | 5.9 | 5.9 | Shrubs | 6.0 | 4.6 |
| *Spiraea* | 9.4 | 4.2 | *Spiraea* | 5.7 | 7.6 |
| Open Water | 7.6 | 2.2 | Open Water | 7.5 | 5.8 |
| Transition-Emergents | 21 | 31 | Transition-Emergents | 33 | 14 |
| Sedges | 29 | 27 | Sedges | 19 | 25 |
| Degraded Sedges | 18 | 15 | Degraded Sedges | 24 | 22 |
| Other Disturbance | 8.3 | 11 | Other Disturbance | 11 | 18 |
| Unclassified | - | 3.0 | Unclassified | - | 1.8 |
| June 25, 1977-Color film | | | October 3, 1977 | | |
| Shrubs | 5.3 | 3.8 | Shrubs | 7.8 | 5.8 |
| *Spiraea* | 8.5 | 11 | *Spiraea* | 9.2 | 7.5 |
| Open Water | 5.5 | 4.8 | Open Water | 10 | 10 |
| Transition-Emergents | 24 | 25 | Transition-Emergents | 25 | 15 |
| Sedges | 25 | 15 | Sedges | 11 | 22 |
| Degraded Sedges | 21 | 23 | Degraded Sedges | 12 | 20 |
| Other Disturbance | 12 | 15 | Other Disturbance | 24 | 17 |
| Unclassified | - | 2.1 | Unclassified | - | 1.3 |

TABLE 25. VEGETATION CLASSES DERIVED USING COMPUTER ASSISTED MAPPING

| Vegetation class | September 25, 1975 | | July 24, 1976 | | June 25, 1977-CIR | | June 25, 1977-Color | |
|---|---|---|---|---|---|---|---|---|
| | $m^2 \times 10^3$ | % | $m^2 \times 10^3$ | % | $m^2 \times 10^3$ | % | $m^2 \times 10^3$ | % |
| *Carex lacustris* | 54 | 22 | | | | | | |
| *Carex stricta* | 44 | 18 | 43 | 18 | 33 | 13 | | |
| Degraded Sedges | | | 37 | 15 | 53 | 21 | 59 | 24 |
| *Spiraea*/Sedges | 44 | 18 | 33 | 13 | 24 | 9.6 | 43 | 17 |
| *Spiraea*/Shrubs | 18 | 7.4 | | | 17 | 6.7 | | |
| Shrubs | 5.7 | 2.3 | 11 | 4.4 | | | 19 | 7.6 |
| Transition | 41 | 17 | | | | | | |
| Emergents | 12 | 4.9 | | | | | | |
| Transition-Emergents | | | 73 | 30 | 42 | 17 | 48 | 20 |
| *Lemna minor* | 4.5 | 1.8 | 26 | 10 | 29 | 12 | 23 | 9.2 |
| Weedy Annuals | | | | | 14 | 5.9 | 25 | 10 |
| Dike | 15 | 6.2 | 8.7 | 3.5 | 4.7 | 1.9 | 12 | 4.8 |
| Open Water | 1.1 | 0.5 | 14 | 5.7 | 20 | 8.1 | 15 | 6.1 |
| Unclassified | 6.0 | 2.4 | 1.0 | 0.4 | 9.7 | 3.9 | 3.0 | 1.2 |
| Total Area | 246 | | 246 | | 246 | | 246 | |

## GENERATING COMPUTER ASSISTED VEGETATION MAPS

Computer assisted vegetation maps based on film dye density data offer consistent classification of a large area and quantification of the area covered by each vegetation class.

Generating computer vegetation maps entails the following steps: 1) Selecting airphotos to be mapped; 2) scanning the imagery to obtain film dye density data; 3) correcting and transforming the data; 4) choosing and "cleaning" the training sets selected, to represent the different vegetation classes observed on the photo; 5) using training set values to assign a classification to each pixel (unit of measurement) that makes up a scene; and 6) classifying the entire scene.

A discussion follows of the two processes, namely, film scanning to obtain dye density data and dye density exposure classification. Lillesand and Kiefer (1979) discuss black and white film characteristics, color film characteristics and color infrared film characteristics.

### Film Scanning

Film density is measured with an instrument called a densitometer. Spot densitometers take density readings on an image by manually translating the image with respect to the instrument optics. When an entire image is to be scanned, a scanning densitometer, which covers the entire image scan line by scan line, is used. Although a scanning densitometer was used to extract airphoto density data for a portion of this study, it is easier to first explain how a spot densitometer works. The scanning densitometer functions in a smilar manner except that it picks up continuous bands of data instead of one spot at a time.

#### Spot Densitometer--

The spot densitometer operates by means of a light source which illuminates the image under study with a reference beam of incident light (Figure 40). The incident light passes through an aperture assembly which allows selection of various image spot sizes. As the film is scanned, it passes between the aperture assembly and a spectral filter assembly so that data from one film layer at a time is collected. Incident light from the light source passes to a receiver--a photo-multiplier tube--which responds electronically to that part of the light beam which has passed through the image. A readout unit displays the receiver response in terms of image density. In this study, image density was expressed as values ranging from 0 to 225. Objects that look very dark (such as water) on an airphoto were

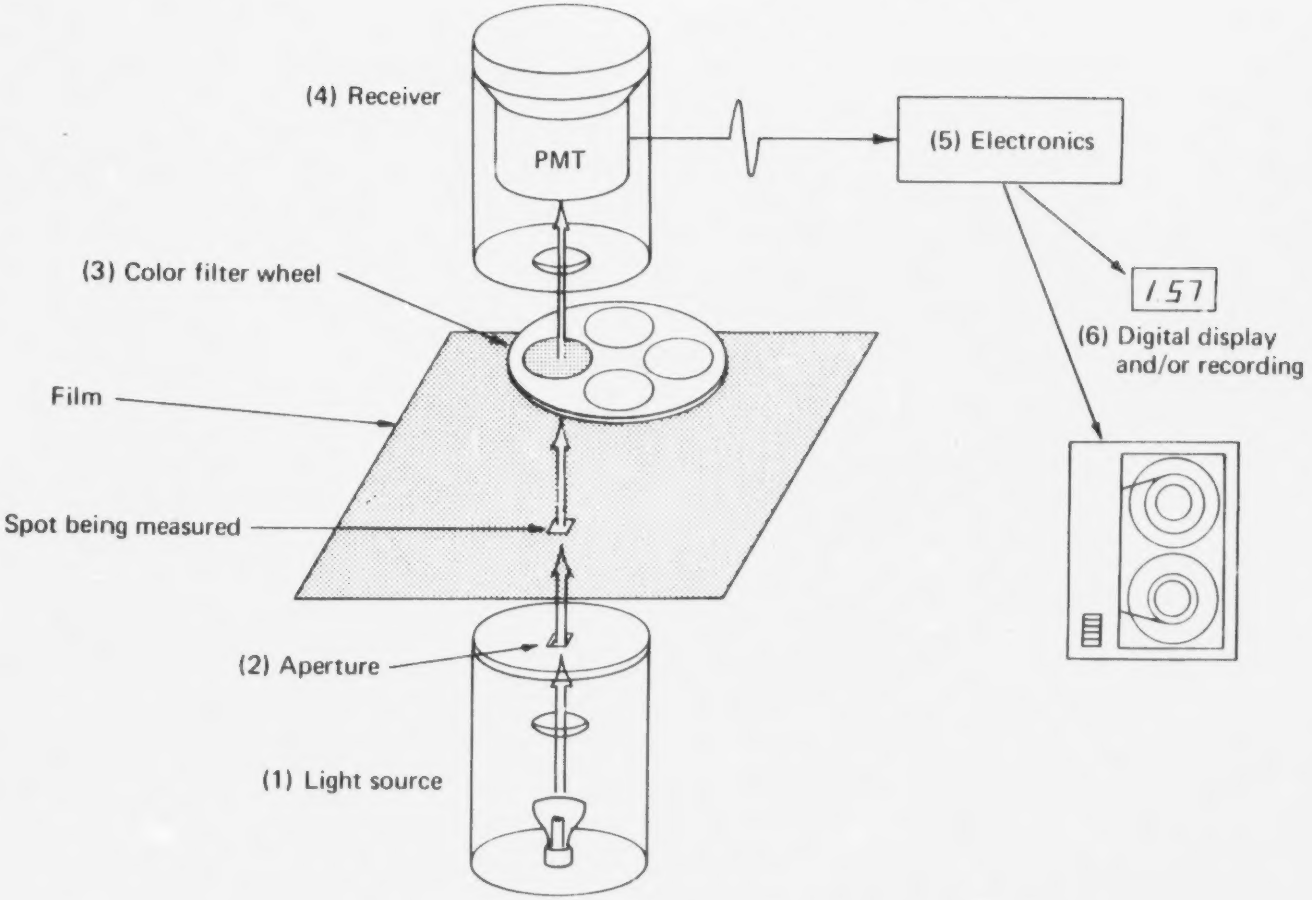

(4) Receiver
PMT
(5) Electronics
(3) Color filter wheel
1.57
(6) Digital display
and/or recording
Film
Spot being measured
(2) Aperture
(1) Light source

Figure 40. Spot densitometer (from Lillesand and Kiefer, 1979).

assigned very low values while very bright objects were assigned very high values.

Scanning Densitometer--

Two types of scanning densitometers exist: flatbed and rotating drum systems. A flatbed system moves the image in a flat plane with respect to the source/receiver optics (Figure 41). Readings are taken at discrete intervals along scan lines. At the end of a line, the instrument steps over and begins the next scan line parallel and contiguous to the previous line. This process is repeated until the entire image has been scanned.

In a rotating drum scanner (Figure 41) the film is mounted over a square hole in a rotating drum such that it forms a portion of the drum's circumference. The image on the drum spins round while the source/optics receiver steps over after each drum rotation.

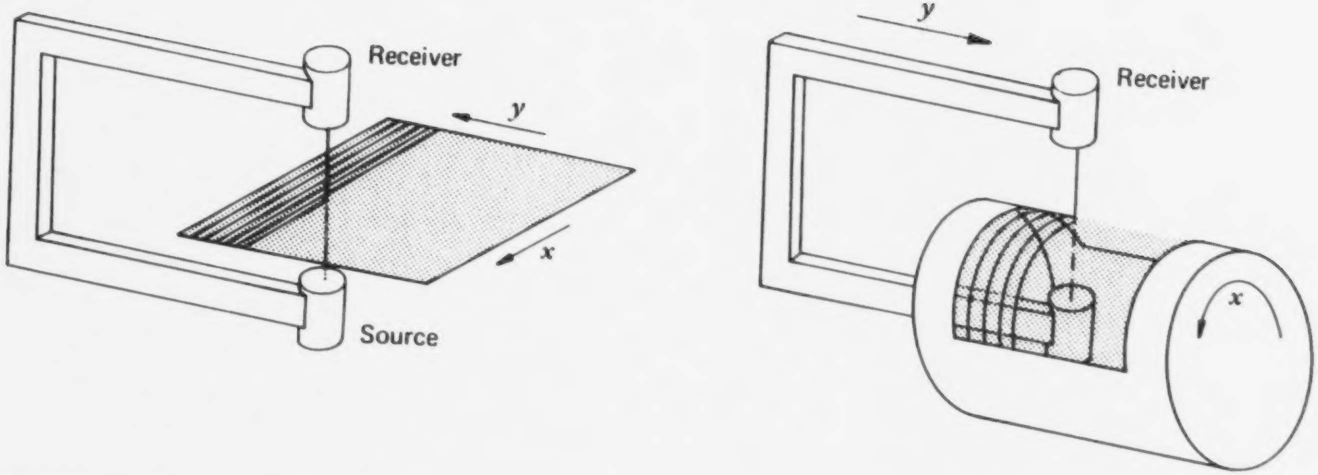
A revolving drum Optronics P 1700 Photomation Mark II Scanning Microdensitometer was used to scan the airphotos and stepwedges. The scanning was done using three 0.012 μm narrow band filters centered at 0.45 μm, 0.55 μm, 0.65 μm in order to extract blue, green, and red film data.

All images scanned were at a scale of 1:38,200. A pixel size of 50 μm was selected which gave an on-the-ground spot size of 1.9 m. As an image is scanned on a scanning microdensitometer, continuous output from the photomultiplier tube is converted to describe integer values on a pixel-by-pixel basis. These density values ranging from 0 to 255 are recorded on computer-compatible seven track tapes (Buchanan 1977, Lillesand and Kiefer 1979).

Input from the scanner is in the form of a two dimensional array of numbers proportional to the dye density. These numbers are written in eight bit words on magnetic tape.

After the scanning process, film density data are available for processing. Since film density measurements reflect the combined broad band sensitivities of all film layers and the film base, film density is not related linearly to film exposure and light reflected from the ground.

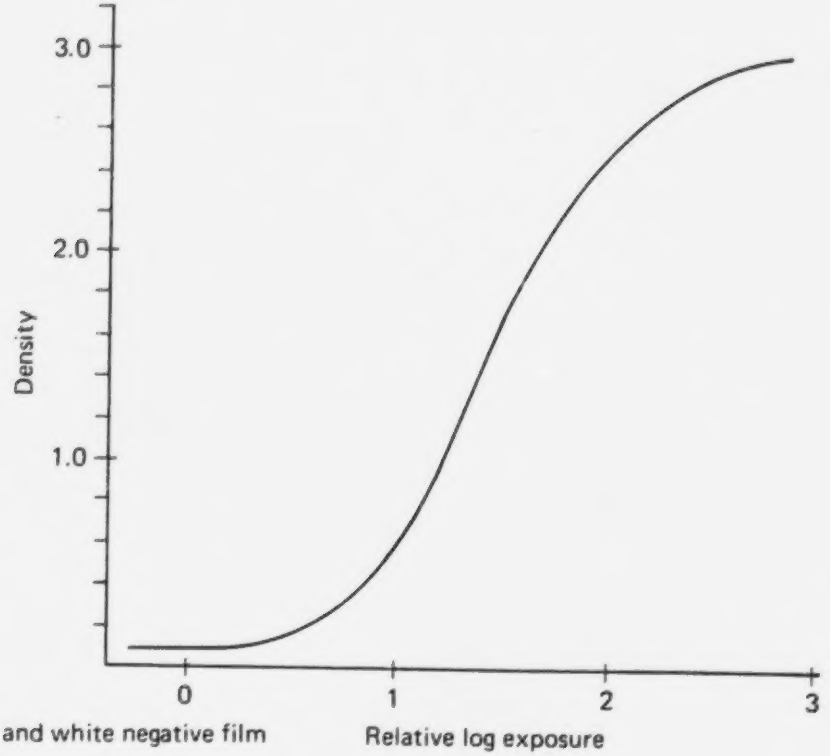
Film exposure on a photo is related to the reflectance of the object imaged at that point. Characteristic curves (often called density log exposure or D-log E curves) are used to relate the exposure values for the photo by the densitometer (Figure 42). (The computer assisted classification process carried out at the University of Wisconsin-Madison is unique since it works with spectral analytical density data (Scarpace 1978). D-log E curves are generated by exposing a portion of a film to a series of known energy steps. This creates a strip of film called a filmwedge, made up of a series of sections or steps, ranging from a very light density to a very dark density. Such a filmwedge provides a quantified incremental scale of densities, each with a known exposure. The D-log E curves make it possible to convert the film densities provided by a densitometer into exposure


Receiver
y
x
Source
y
Receiver
x

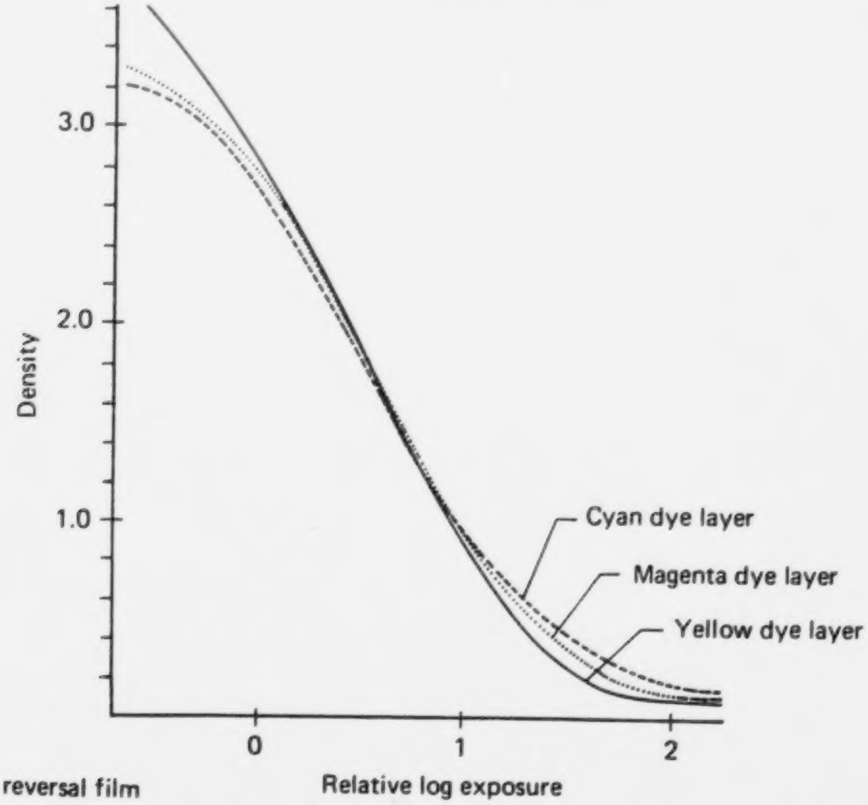
*(a)* Flatbed version

*(b)* Drum version

Figure 41. Two types of scanning microdensitometers: In the flatbed version, the image scanned moves in relation to source/receiver, in the drum version, the drum and source/receiver move (from Lillesand and Kiefer, 1979).



*(a)* Black and white negative film



*(b)* Color reversal film

Figure 42. D-log E curves (from Lillesand and Kiefer, 1979).

values. Exposure data can be correlated directly with ground phenomena (Scarpace 1978).

## Flim Data Classification

A number of computer programs have been developed in the Environmental Remote Sensing Center at the University of Wisconsin-Madison to input, output, correct, analyze, transform and classify film density data (Scarpace, Fisher, and Quirk 1978). Program DLOGE uses scanned density values and established log exposure values to create D-log E curves for the yellow, magenta, and cyan film layers (Figure 43).

### Correcting and Transforming Data--

Program CORRECT corrects the scanned data by transforming the density values recorded with the scanning microdensitometer to nonlinear exposure values using the D-log E curves generated by program DLOGE and user supplied information about the exposure ranges to be used for output values. In essence, the analyst defines the linear portion of each D-log E curve by entering exposure values A and B (Figure 44). The interval between A and B is divided into 256 equal width increments of log exposure, and each is assigned a value between 0 and 255. CORRECT converts the original density data values to log exposure values. At the same time CORRECT generates D-log E curves for all three film layers of data (Figure 45).

Lens falloff, which causes vignetting toward the edges of the film image also must be corrected as it prevents vegetation response signatures from being consistent across the image. Program FALLOFF corrects the log exposure values for lens falloff in one of two ways:

if the cosine option is chosen, the effect of lens falloff is assumed to be expressed as

$$E(r) = E(o)\cos^n\theta \quad \log E(r) = \log E(o) + \log [\cos^n(\theta)] \qquad (1)$$

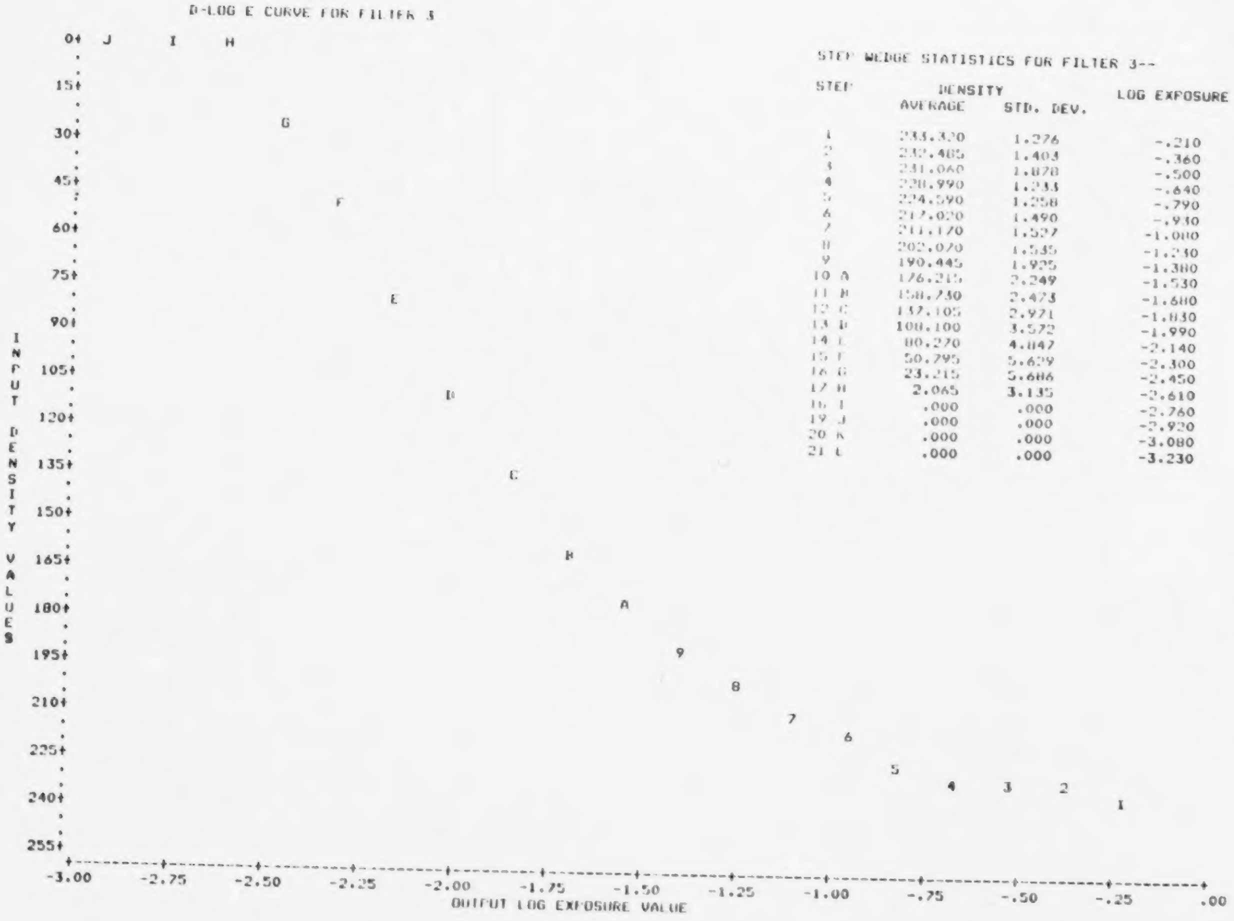
where:

$E(r)$ is the exposure at a distance r from the center,

$E(o)$ is the exposure at the center and

$\xi$ is the angular distance from the lens axis.

(The program computes a look-up table of the value log ($\cos^n\theta$) if the table option is used and the distance of any point in the data-file from the center row, column must be < 1650 pixels.) For each pixel in the data-file, the log exposure and distance from center are calculated. The log exposure



```
STEP WEDGE STATISTICS FOR FILTER 3--
STEP          DENSITY              LOG EXPOSURE
         AVERAGE    STD. DEV.

  1      233.320      1.276           -.210
  2      232.485      1.403           -.360
  3      231.060      1.878           -.500
  4      228.990      1.233           -.640
  5      224.590      1.258           -.790
  6      217.020      1.490           -.930
  7      211.170      1.527          -1.080
  8      202.070      1.535          -1.230
  9      190.445      1.925          -1.380
 10 A    176.215      2.249          -1.530
 11 B    158.730      2.473          -1.680
 12 C    137.105      2.971          -1.830
 13 D    108.100      3.572          -1.990
 14 E     80.270      4.847          -2.140
 15 F     50.795      5.629          -2.300
 16 G     23.215      5.686          -2.450
 17 H      2.065      3.135          -2.610
 18 I       .000       .000          -2.760
 19 J       .000       .000          -2.920
 20 K       .000       .000          -3.080
 21 L       .000       .000          -3.230
```

Figure 43. Output from program DLOGE.

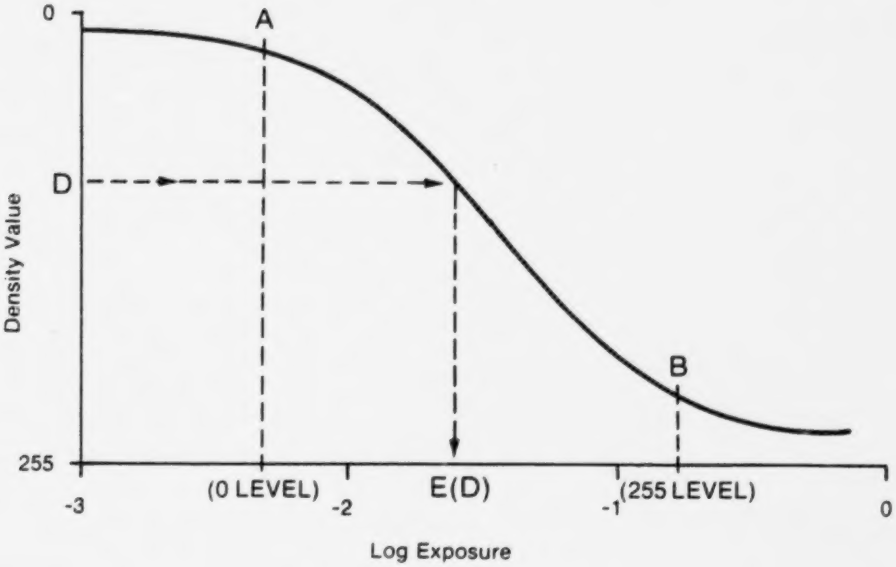


Figure 44. Density to log exposure correction using program CORRECT.

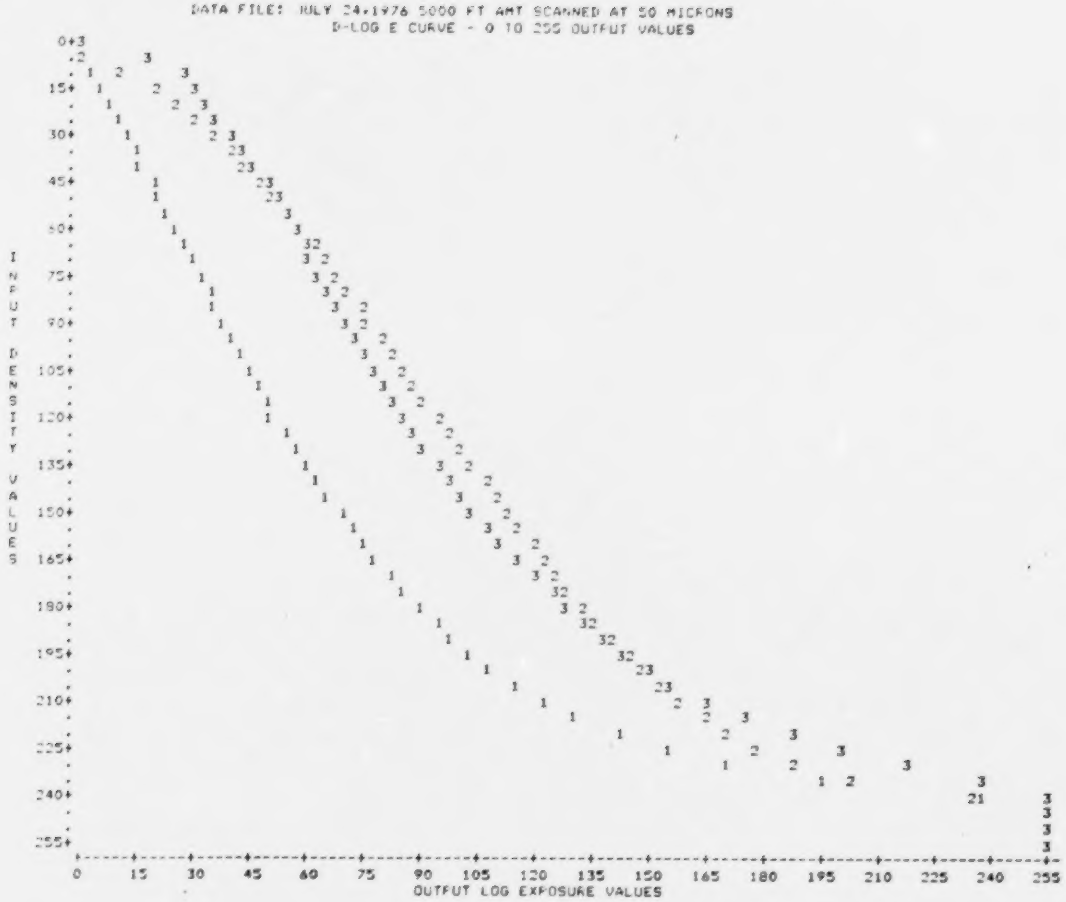


Figure 45. D-log E curves generated by program CORRECT.

value is corrected by subtracting the look-up table value corresponding to r from the pixel's log E value.

If the table option is chosen then the effect of lens falloff can be expressed as:

$$E(r) = E(o)T(r) \quad \log E(r) = \log Eo + \log (T(r)) \qquad (2)$$

where:

T(r) is the falloff factor at distance r.

The T(r) values were measured at Johnson Spacecraft Center for a variety of lens, filter and F/stop combinations. Each table represents one element of the film, and corresponds to one lens-filter-F/stop combination (Kalman and Scarpace 1979).

The tables contain T(r) values for r going from 0 to 38 mm, in steps of 1 mm. The FALLOFF program interpolates in the table, and generates a look-up table of log T(r) for r with this option. The distance of any point in the data-file from the center must be < 500 pixels. If the cosine option is used, the distance from the center to any pixel must be < 1650 pixels. The log exposure value and distance r for each pixel in the data file are computed. The log exposure is corrected by subtracting log T(r). Corrected log exposure values are stored in a data file.

### Transforming and Enhancing the Data--

Several programs are available to transform and enhance data and separate vegetation response patterns. Two of the programs which seemed particularly useful are NORMRATIO and SMOOTH.

Program NORMRATIO calculates a normalized ratio of the bands of film or scanner data. The program calculates

$$R_A = \frac{A - 255}{(A^2 + B^2 + C^2 + D^2)^{1/2}} \qquad (3)$$

where:

$R_A$ is the value representing the calculated value of the normratio for band 4, and

A, B, C, and D are the values for bands 4, 5, 6, and 7 for each pixel.

The program redefines values below zero or > 255 to zero or 255 and places the calculated value in the appropriate bands of the new data-file.

Program SMOOTH can be used to generalize density slice or classified scene data, smoothing out aberrant pixels and generating a more map-like classification than the original classification.

Each pixel of the classified scene is processed in a sequential manner. Each pixel and its immediate neighbors are examined and a determination is made as to whether or not a majority of the pixels belong to the same class. If the majority of the pixels belong to the same class, the central pixel of the neighborhood (i.e., the pixel under examination) is assigned (reclassified) to the majority of class. The one exception to this generalization scheme occurs when the majority class is the "unclassified" class. For this case the central pixel is not changed, but retains its original classification.

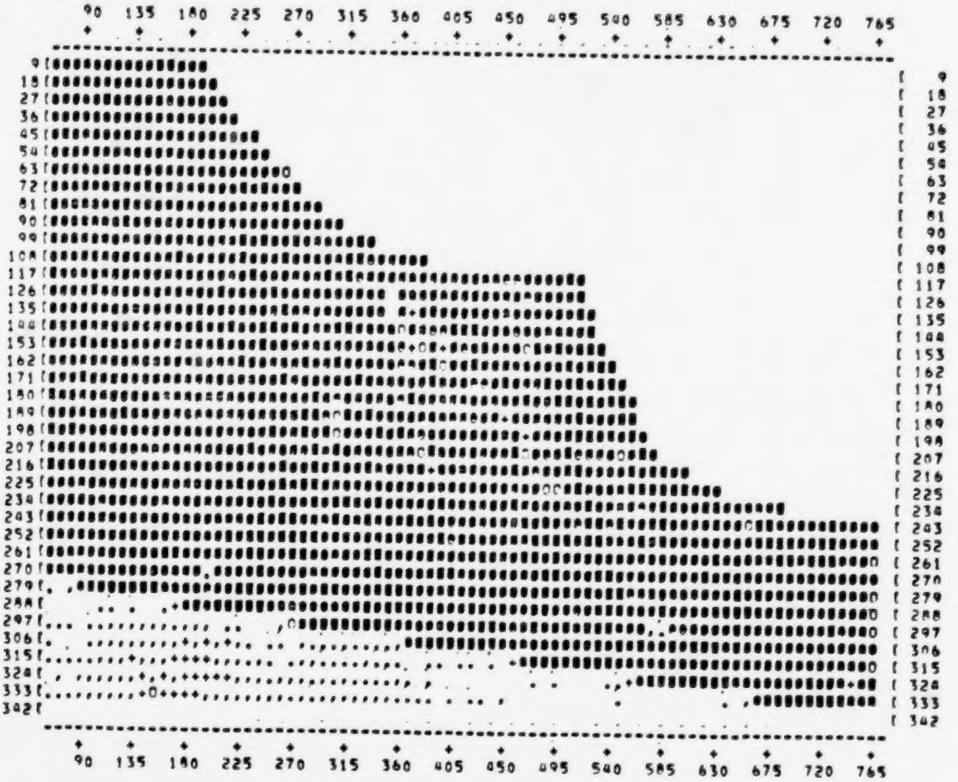
### Selecting Training Sets--

Once the data are corrected and transformed, training sets of the various resources are selected. To assist in the average set selection, program SLICE was used to generate 10 and 36 level density slices for each band of data (Figures 46 and 47). A 10 level slice is most helpful for identifying broad patterns. A 36 level slice should be used to delineate the details within broad patterns for training set selection.

Training set selection is extremely important as a supervised classification can only be as good as the training sets which are selected to define the resources and form the basis of classification (Wacker and Landgrebe 1972). In this study training sets were selected using a 36 level slice. Any area on a density slice consisting of 20 or more pixels with the same symbol was a potential training set. In most instances training sets could be confidently identified as a particular vegetation class only when an entire scene was classified, making it possible to see all the locations designated for that training class.

The actual location of a training set is specified, by entering into the computer density slice row and column values of the apices of the area. The computer lists the name of each training set, its corrected and uncorrected apex points and the number of data points in each training set (Figure 48). The number of pixels necessary for each training set should be between 10 n and 100 n where n equals the number of spectral bands of data being used. Training sets for one vegetation class should come from all over the scene being classified rather than using one large training set located in a single area. The spread of training sets over an entire scene for a single vegetation class increases the change that the training data will be representative of all variations in the data throughout the scene (Lillesand and Kiefer 1979).

```
JUNE 1977 CIR 5000 FT AMT 40 MM LENS SCANNED AT 50 MICRONS
ROWS--   9 TO  342   COLUMNS--  63 TO  774
EVERY  9 ROWS AND COLUMNS ARE  SHOWN
SLICED ON BAND   6
```

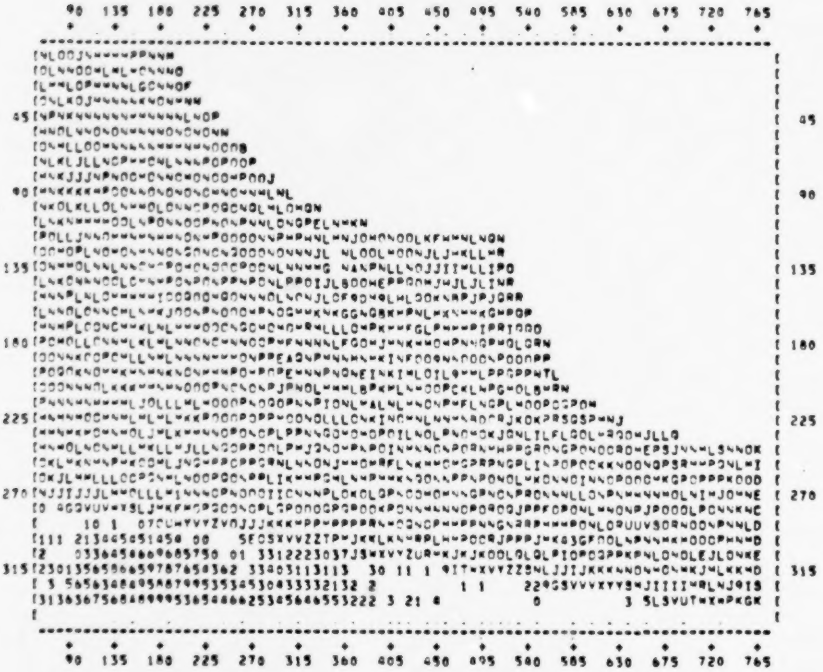


```
VALUES BELOW  10  ARE BLANK

 10  35  60  85 110 135 160 185 210
 TO  TO  TO  TO  TO  TO  TO  TO AND
 34  59  84 109 134 159 184 209  UP
... ,,, +++ 000 ■■■ ■■■ ■■■ ■■■ ■■■
... ,,, +++ 000 ■■■ ■■■ ■■■ ■■■ ■■■
... ,,, +++ 000 ■■■ ■■■ ■■■ ■■■ ■■■
```

Figure 46. Overprinted 10-level density slice.

```
JUNE 1977 CIR 5000 FT AMT 40 MM LENS SCANNED AT 50 MICRONS
ROWS--   9 TO  342   COLUMNS--  63 TO  774
EVERY  9 ROWS AND COLUMNS ARE  SHOWN
SLICED ON BAND   6
```



```
VALUES BELOW  10  ARE BLANK

 10  17  24  31  38  45  52  59  66  73  80  87  94 101 108
 TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO
 16  23  30  37  44  51  58  65  72  79  86  93 100 107 114
000 111 222 333 444 555 666 777 888 999 AAA BBB CCC DDD EEE
000 111 222 333 444 555 666 777 888 999 AAA BBB CCC DDD EEE
000 111 222 333 444 555 666 777 888 999 AAA BBB CCC DDD EEE

115 122 129 136 143 150 157 164 171 178 185 192 199 206 213
 TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO  TO
121 128 135 142 149 156 163 170 177 184 191 198 205 212 219
FFF GGG HHH III JJJ KKK LLL MMM NNN OOO PPP QQQ RRR SSS TTT
FFF GGG HHH III JJJ KKK LLL MMM NNN OOO PPP QQQ RRR SSS TTT
FFF GGG HHH III JJJ KKK LLL MMM NNN OOO PPP QQQ RRR SSS TTT

220 227 234 241 248 255
 TO  TO  TO  TO  TO AND
226 233 240 247 254  UP
UUU VVV WWW XXX YYY ZZZ
UUU VVV WWW XXX YYY ZZZ
UUU VVV WWW XXX YYY ZZZ
```

Figure 47.  A 36-level density slice.

```
@XQT RS*FS.TRAIN

 TRAIN VERSION 2.1  --  09 JANUARY 1978
     RUN AT 21:05:57    ON 03/10/79
 SHOW THE TRAINING SET PICTURE (YES OR NO)?--
NO

 DATA-FILE IS
 SEPTEMBER 1975 CIR 5000 FT AMT SCANNED AT 50 MICRONS

 NO PREVIOUS TRAINING SETS.
 APEX LIST?--
428 224 440 N\N240
 MORE APEXES OR CLASS NAME?--
A WATER
        CLASS  1--A WATER
        UNCORRECTED APEX POINTS--
        ( 428, 224) ( 440, 240)
        CORRECTED APEX POINTS--
        ( 428, 224) ( 428, 240) ( 440, 240) ( 440, 224)
         221 DATA POINTS FILED IN FILE 20

 APEX LIST?--
330 194 334 240
 MORE APEXES OR CLASS NAME?--
A DIKE
        CLASS  2--A DIKE
        UNCORRECTED APEX POINTS--
        ( 330, 194) ( 334, 240)
        CORRECTED APEX POINTS--
        ( 330, 194) ( 330, 240) ( 334, 240) ( 334, 194)
         235 DATA POINTS FILED IN FILE 20

 APEX LIST?--
400 110 410 130
 MORE APEXES OR CLASS NAME?--
A WATER
        CLASS  3--A WATER
        UNCORRECTED APEX POINTS--
        ( 400, 110) ( 410, 130)
        CORRECTED APEX POINTS--
        ( 400, 110) ( 400, 130) ( 410, 130) ( 410, 110)
         231 DATA POINTS FILED IN FILE 20

 APEX LIST?--
250 110 260 120
 MORE APEXES OR CLASS NAME?--
A C,D
        CLASS  4--A C,D
        UNCORRECTED APEX POINTS--
        ( 250, 110) ( 260, 120)
        CORRECTED APEX POINTS--
        ( 250, 110) ( 250, 120) ( 260, 120) ( 260, 110)
         121 DATA POINTS FILED IN FILE 20
```

Figure 48. Listing provided by program TRAIN.

Programs CLASSBAR, HSGRAM (histogram), and SCATTER (scatter diagrams) are used to view and better define training set data. Program CLASSBAR prints out bar diagrams for each spectral band in order to show the mean spectral response of each class and the variance of the distribution. Mean values are designated by a 0 and standard deviations by 1, 2, and 3 (Figure 49). These bar diagrams show where classes overlap in spectral bands and which bands can best be used to discriminate classes. While bar diagrams show how vegetation response patterns relate to one another or how badly they may be confounded, they are not detailed enough to define specific boundaries (Buchanan 1977).

Program HSGRAM plots histograms for any or all training sets filed using Program TRAIN (Figure 50). The histograms plot the number of points in a training set for the range of brightness values displayed. Histogram output is important when using a maximum likelihood classifier (which requires normally distributed data) as a histogram provides a visual check on the normality of training set data. Separate histograms are produced for each color band, permitting fairly exact spectral selection for training sets. If multiple vegetation classes are included in a training set, a histogram may show a bi-modal or multi-modal distribution. Sometimes a bi-modal distribution stems from different illumination conditions within the same training class. The resulting subclasses must be separated to get a good classification.

Program SCATTER can help separate training sets that include two or more vegetation classes. SCATTER produces scatter diagrams of training set values, plotting two bands of brightness value data against each other. Multiclass signatures often show up as separate ellipses in the scatter diagram. Exposure value can be determined for all three bands by viewing scatter diagrams (Figure 51). Use of the above programs allows the user to determine the quality of the selected training sets.

Training sets can be modified by use of the programs MODSET (modification of training sets), CLEANTR (cleans training sets), and CLSTRN (class train). MODSET offers the following options: 1) several training sets may be merged into one; 2) selected training sets may be deleted; 3) the name of a training set may be changed; 4) training sets may be reordered; 5) training set reponse patterns may be restricted to within a specified number of standard deviations; and 6) arbitrary upper and lower bounds can be imposed on training sets whereby extraneous pixels are removed.

Program CLEANTR was designed to provide a statistical clean-up of training sets. This program allows the analyst to specify the number of standard deviations beyond which data values will be deleted (Figure 52).

Program CLSTRN creates two matrices of all training sets selected for a specific classification. This program runs a maximum likelihood test on each training class' pixels as to whether they are most similar to themselves or to other classes defined by other groups of pixels. If the training sets are independent of one another, most of the points in any training set are classified as belonging to that training set. The first

```
        SEPTEMBER 1975 CIR 5000 FT AMT SCANNED AT 50 MICRONS                            BAND  6
                                                     11111111111111111111111111111111111111111111111111222222222222222222222222222222
        11111222223333344444555556666677777888889999900000111112222233333444445555566666777778888899999000001111122222333334444455555
   02468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024
 1                                                3*21-01-* 3
 2                                                           3*2-1--0-1-2*3
 3                                                            3*1-01*3
 4                                                              3*-1012*3
 5                                                          *21-01-*3
 6                                                 3*2-1--0-1-2-*3
 7                                                         3 *-1-0-1-* 3
 8                                                            3*2-1-01-2*3
 9                                                                      *21-01-*3
10                                                        3 *-2--1--0---1--2-* 3
11                                                              3 *2--1--0--1--2*3
12                                              3  *2---1---0---1----2-* 3
13                                                                 3 *-1-0-1-2*3
14                                             3*-1-01-2*3
15                                                                        3*2-10-1-*3
16                                                          3 *2--1---0--1--2* 3
17                                                               3 2*1--0-1*2 3
18                                                                 3 *-1--0-1-2*3
                                                     11111111111111111111111111111111111111111111111111222222222222222222222222222222
        11111222223333344444555556666677777888889999900000111112222233333444445555566666777778888899999000001111122222333334444455555
   02468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024680246802468024
```

Figure 49. Bar diagrams generated by program CLASSBAR.

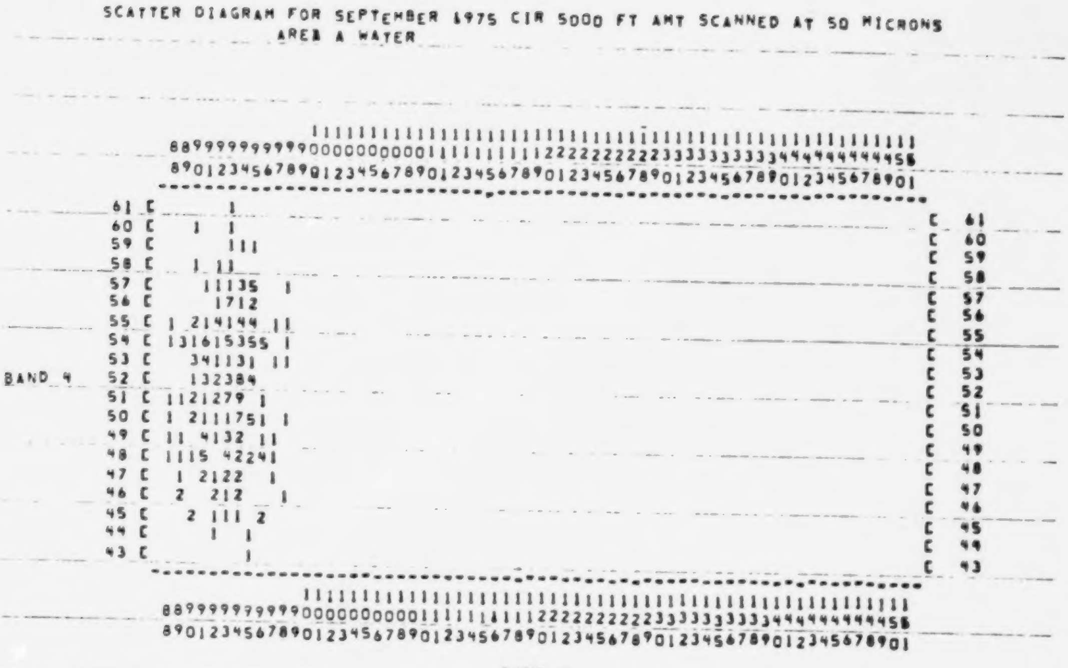
```
CLASS 13--WATER

        20  POINTS PER SYMBOL.        425  POINTS IN ENTIRE HISTOGRAM.

              BAND 4                        BAND 5                        BAND 6
   0+                            0+                            0+*****************
   2I                            2I                            2I
   4I                            4I                            4I
   6I                            6I                            6I
   8I                            8I                            8I
  10+                           10+                           10+
  12I                           12I                           12I
  14I                           14I                           14I*
  16I                           16I                           16I
  18I                           18I                           18I
  20+                           20+                           20+
  22I                           22I                           22I
  24I                           24I                           24I
  26I                           26I                           26I*
  28I                           28I                           28I*
  30+                           30+                           30+*
  32I                           32I                           32I
  34I                           34I                           34I
  36I                           36I                           36I
  38I                           38I                           38I
  40+                           40+                           40+
  42I                           42I                           42I
  44I                           44I                           44I
  46I                           46I                           46I
  48I*                          48I                           48I
  50+**                         50+                           50+
  52I*****                      52I                           52I
  54I****                       54I                           54I
  56I***                        56I                           56I
  58I**                         58I                           58I
  60+**                         60+                           60+
  62I*                          62I                           62I
  64I                           64I                           64I
  66I                           66I                           66I
  68I                           68I                           68I
  70+                           70+                           70+
  72I                           72I                           72I
  74I                           74I                           74I
  76I                           76I                           76I
  78I                           78I                           78I
  80+                           80+                           80+
  82I                           82I                           82I
  84I                           84I                           84I
  86I                           86I                           86I
  88I                           88I                           88I
  90+                           90+*                          90+
  92I                           92I*****                      92I
  94I                           94I*****                      94I
  96I                           96I******                     96I
  98I                           98I***                        98I
 100+                          100+*                         100+
```

Figure 50. Histograms created by program HSGRAM.

Reproduced from best available copy.

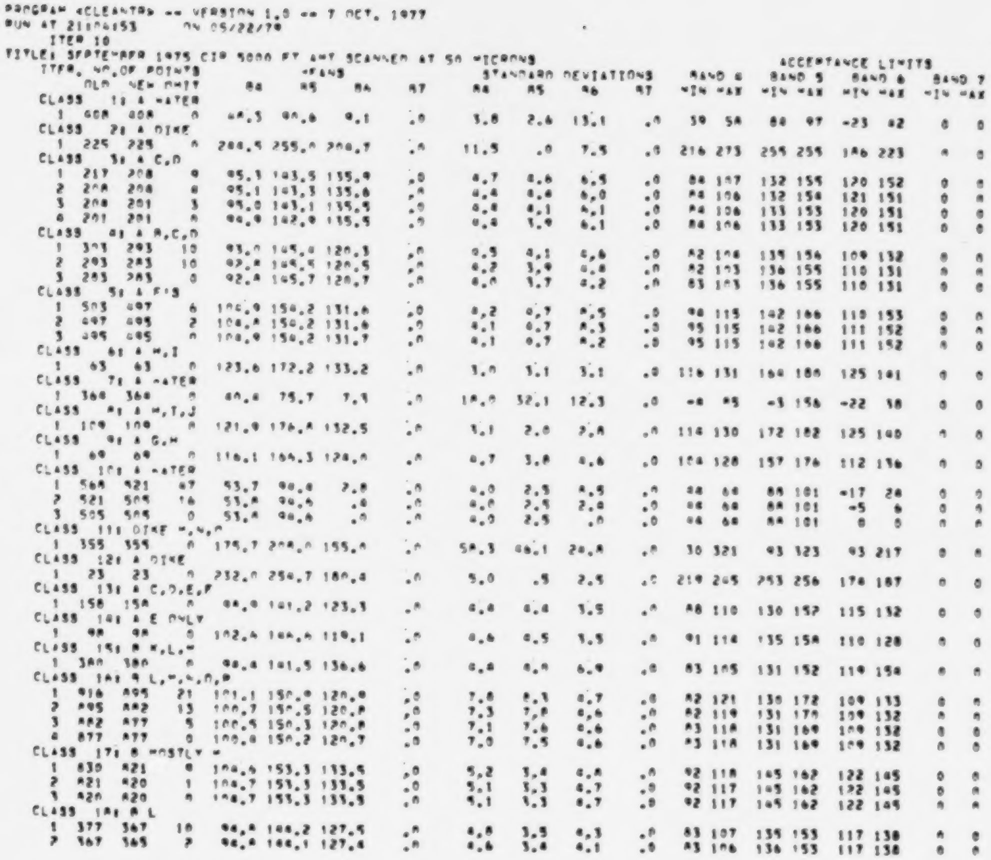


```
          SCATTER DIAGRAM FOR SEPTEMBER 1975 CIR 5000 FT AMT SCANNED AT 50 MICRONS
                         AREA A WATER

                            1111111111111111111111111111111111111111111111111111
                8899999999990000000000111111111122222222223333333333444444444455
                8901234567890123456789012345678901234567890123456789012345678901
               ------------------------------------------------------------------
           61 [      1
           60 [   1  1                                                           [  61
           59 [      111                                                         [  60
           58 [   1 11                                                           [  59
           57 [    11135  1                                                      [  58
           56 [     1712                                                         [  57
           55 [ 1 214144 11                                                      [  56
           54 [ 131615355 1                                                      [  55
           53 [   341131 11                                                      [  54
BAND 4     52 [   132384                                                         [  53
           51 [ 1121279 1                                                        [  52
           50 [ 1 2111751 1                                                      [  51
           49 [ 11 4132 11                                                       [  50
           48 [ 1115 42241                                                       [  49
           47 [  1 2122  1                                                       [  48
           46 [  2  212   1                                                      [  47
           45 [   2 111 2                                                        [  46
           44 [     1  1                                                         [  45
           43 [        1                                                         [  44
               ------------------------------------------------------------------[  43
                            1111111111111111111111111111111111111111111111111111
                8899999999990000000000111111111122222222223333333333444444444455
                8901234567890123456789012345678901234567890123456789012345678901

                                            BAND 5
```

Figure 51. Scatter diagram created by program SCATTER.



```
PROGRAM <CLEANTR> -- VERSION 1.0 -- 7 OCT. 1977
RUN AT 21:04:53     ON 05/22/79
   ITER 10
TITLE: SEPTEMBER 1975 CIR 5000 FT AMT SCANNED AT 50 MICRONS                                ACCEPTANCE LIMITS
   ITER, NO.OF POINTS           MEANS                     STANDARD DEVIATIONS       BAND 4   BAND 5   BAND 6   BAND 7
       OLD  NEW OMIT      B4    B5    B6     B7       B4    B5    B6     B7     MIN MAX  MIN MAX  MIN MAX  MIN MAX
  CLASS   1: A WATER
    1  408  408    0   48.5  90.6   9.1    .0      3.8   2.6  13.1     .0      39  58   84  97  -23  42    0   0
  CLASS   2: A DIKE
    1  225  225    0  244.5 255.0 204.7    .0     11.5    .0   7.5     .0     216 273  255 255  186 223    0   0
  CLASS   3: A C,D
    1  217  208    9   95.1 143.5 135.9    .0      4.7   4.6   6.5     .0      84 107  132 155  120 152    0   0
    2  208  204    4   95.1 143.3 135.6    .0      4.4   4.4   6.0     .0      84 106  132 154  121 151    0   0
    3  204  201    3   95.0 143.1 135.5    .0      4.4   4.1   6.1     .0      84 106  133 153  120 151    0   0
    4  201  201    0   94.9 142.9 135.5    .0      4.4   3.9   6.1     .0      84 106  133 153  120 151    0   0
  CLASS   4: A B,C,D
    1  303  293   10   93.0 145.4 120.3    .0      4.5   4.1   4.6     .0      82 104  135 156  109 132    0   0
    2  293  283   10   92.8 145.5 120.5    .0      4.2   3.9   4.4     .0      82 103  136 155  110 131    0   0
    3  283  283    0   92.4 145.7 120.7    .0      4.0   3.7   4.2     .0      83 103  136 155  110 131    0   0
  CLASS   5: A F,G
    1  503  497    6  104.9 154.2 131.6    .0      4.2   4.7   8.5     .0      94 115  142 166  110 153    0   0
    2  497  495    2  104.8 154.2 131.6    .0      4.1   4.7   8.3     .0      95 115  142 166  111 152    0   0
    3  495  495    0  104.9 154.2 131.7    .0      4.1   4.7   8.2     .0      95 115  142 166  111 152    0   0
  CLASS   6: A H,I
    1   63   63    0  123.6 172.2 133.2    .0      3.0   3.1   3.1     .0     116 131  164 180  125 141    0   0
  CLASS   7: A WATER
    1  364  364    0   40.4  75.7   7.3    .0     18.0  32.1  12.3     .0      -4  85   -5 156  -22  38    0   0
  CLASS   8: A H,I,J
    1  109  109    0  121.9 176.8 132.5    .0      3.1   2.0   2.8     .0     114 130  172 182  125 140    0   0
  CLASS   9: A G,H
    1   69   69    0  116.1 166.3 124.0    .0      4.7   3.8   4.6     .0     104 128  157 176  112 136    0   0
  CLASS  10: A WATER
    1  568  521   47   53.7  94.4   2.8    .0      4.0   2.5   8.5     .0      44  64   88 101  -17  24    0   0
    2  521  505   16   53.8  94.6    .4    .0      4.0   2.5   2.0     .0      44  64   88 101   -5   6    0   0
    3  505  505    0   53.8  94.6    .0    .0      4.0   2.5    .0     .0      44  64   88 101    0   0    0   0
  CLASS  11: DIKE M,N,O
    1  355  355    0  175.7 208.0 155.0    .0     58.3  46.1  24.8     .0      30 321   93 323   93 217    0   0
  CLASS  12: A DIKE
    1   23   23    0  232.0 254.7 180.4    .0      5.0    .5   2.5     .0     219 245  253 256  174 187    0   0
  CLASS  13: A C,D,E,F
    1  158  158    0   99.0 141.2 123.3    .0      4.4   4.4   3.5     .0      88 110  130 152  115 132    0   0
  CLASS  14: A E ONLY
    1   98   98    0  102.4 146.6 119.1    .0      4.6   4.5   3.5     .0      91 114  135 158  110 128    0   0
  CLASS  15: B K,L,M
    1  380  380    0   94.4 141.5 136.6    .0      4.4   4.0   6.9     .0      83 105  131 152  119 154    0   0
  CLASS  16: B L,M,N,O,P
    1  916  895   21  101.1 150.4 120.4    .0      7.8   8.3   4.7     .0      82 121  130 172  109 133    0   0
    2  895  882   13  100.7 150.5 120.8    .0      7.3   7.8   4.6     .0      82 119  131 170  109 132    0   0
    3  882  877    5  100.5 150.3 120.8    .0      7.1   7.6   4.6     .0      83 118  131 169  109 132    0   0
    4  877  877    0  100.4 150.2 120.7    .0      7.0   7.5   4.6     .0      83 118  131 169  109 132    0   0
  CLASS  17: B MOSTLY M
    1  830  821    9  104.6 153.3 133.5    .0      5.2   3.4   4.8     .0      92 118  145 162  122 145    0   0
    2  821  820    1  104.7 153.3 133.5    .0      5.1   3.3   4.7     .0      92 117  145 162  122 145    0   0
    3  820  820    0  104.7 153.3 133.5    .0      5.1   3.3   4.7     .0      92 117  145 162  122 145    0   0
  CLASS  18: B L
    1  377  367   10   94.8 144.2 127.5    .0      4.8   3.5   4.3     .0      83 107  135 153  117 138    0   0
    2  367  365    2   94.8 144.1 127.4    .0      4.6   3.4   4.1     .0      83 106  136 153  117 138    0   0
```

Figure 52. Output from program CLEANTR.

matrix lists how many pixels selected to define each class truly define that class. The second matrix expresses this same information as percentages (Figure 53). This program is a particularly useful training set modification program when used in conjunction with program CLASSBAR. (CLASSBAR displays the range of brightness value for each training class for each band (Figure 49).) Program CLSTRN suggests which classes might successfully be combined while program CLASSBAR displays training set bounds for each class, allowing the analyst to decide whether or not it is reasonable to combine one class with another.

### Classifying the Data--

The basic concept behind supervised classification programs is that the spectral response signature of each pixel is compared to the spectral response signatures of the training sets and classified for the best fit. Three classifiers were used in this study--a parallelepiped, or box classifier, an elliptical classifier and a maximum liklihood classifier.

When using a parallelepiped classifier, the lowest and highest brightness values for each band that characterize the different classes are entered into the computer (Figure 54). These values define a rectangular area in a two band scatter diagram or in general for a three dimensional parallelepiped, hence the name parallelepiped classifier (Figure 55). Each pixel is classified according to the classes defined. If a pixel doesn't fit any of the classes, it is put into an unknown category.

The parallelepiped classifier is a fast and efficient and therefore inexpensive classifier. There is a problem with overlap of classes, however, and if a pixel falls into one of these overlap areas, it generally is arbitrarily placed in one of the two classes. To quote Lillesand and Kiefer (1979), "Overlap is caused largely because category distributions which exhibit correlations are poorly described by the rectangular decision regions. Correlation is the tendency of spectral values to vary similarly in two bands, resulting in slanting clouds of observations on scatter diagrams." Where there is correlation, rectangular decision regions poorly fit the class training data, resulting in confusion for the classifier. The overlap problem within a parallelepiped classification can be helped however by breaking the single rectangle that defines each decision region into a series of rectangles whose stepped borders more closely describe the distributions (Figure 56).

More sophisticated classifiers rely on the statistics of each training set to classify a scene pixel by pixel. A maximum likelihood classifier assumes that training set points are distributed normally and with airphoto and multispectral scanner data, this is generally a reasonable assumption (Lillesand and Kiefer 1979) (Figure 57).

When using a maximum likelihood classifier, training sets are evaluated to determine their category spectral response pattern. This pattern can be completely described by the mean vector and covariance matrix (which

```
CLASS           NAME            SIZE  PERCENTAGE OF POINTS CLASSIFIED AS CLASS
                                          1     2     3     4     5     6     7     8     9    10    11    12    13    14    15
   1   C E,F                     150   74.7    .0    .0    .0    .0  19.3    .0    .0    .0    .0    .0   2.0    .0   4.0    .0
   2   C I,J                     166     .0  22.3  16.9  20.5    .0    .0   1.2   6.6   1.2   4.2   6.0   1.8   4.8    .0    .0
   3   C I                        59     .0   5.1  59.3   8.5   1.7    .0   1.7  16.9    .0   6.8    .0    .0    .0    .0    .0
   4   C J                       166     .0   3.0  12.7  68.1    .0    .0    .0   1.8    .0   4.8   8.4    .0   1.2    .0    .0
   5   C G,H                     149     .0    .0   2.7    .0  63.8   2.0  22.8   2.7    .0   2.0    .0   4.0    .0    .0    .0
   6   C E,F                     408   30.4    .0    .0    .0   5.6  48.0   1.0    .0    .0    .2    .0   8.6    .0   6.1    .0
   7   C H                        74     .0   1.4   9.5   1.4  25.7   1.4  47.3  13.5    .0    .0    .0    .0    .0    .0    .0
   8   C MOSTLY I                161     .0  11.8  30.4   7.5   6.2    .0  11.8  27.3    .0   2.5   1.9    .0    .6    .0    .0
   9   C K,L                     109     .0    .0    .0    .0    .0    .0    .0    .0  83.5    .0    .0    .0    .0    .0    .9
  10   C H,I,J,K                 402     .0   3.3  13.0  16.9   4.7    .4   3.3   5.5    .0  26.4   8.3   7.1   9.1    .0    .2
  11   C I,J,K                   309     .0   4.2   5.5  10.0    .0    .0   1.3   6.1    .0   2.9  41.1    .0  22.0    .0   5.5
  12   C F,G,H                   339    9.7   1.8   2.7   1.2   9.1  13.9   2.1   1.5    .0   4.4    .0  51.0    .0   1.8    .0
  13   C J,K,L                   157     .0    .0    .0   2.5    .0    .0    .0    .0    .0   3.8  12.7    .0  77.7    .0   1.9
  14   C D                       163    3.1    .0    .0    .0    .0   2.5    .0    .0    .0    .0    .0   1.2    .0  93.3    .0
  15   C K                       135     .0    .0    .0    .0    .0    .0    .0    .0    .0    .0   5.2    .0   1.5    .0  93.3
```

Figure 53. Percentage matrix from program CLSTRN.

```
TITLE: JUNE 1977 CIR 5000 FT AMT 40 MM LENS SCANNED AT 50 MICRONS
FILE RESOLUTION: 1     PRINT RESOLUTION: 2


CHARACTER    RESOURCE               BAND  LOW   UP  BAND  LOW   UP  BAND  LOW   UP
    W        A WATER O                4     8   12    5    54   76    6     0    4
    2        A 6,7                    4    46   72    5   100  120    6   136  176
    3        A MOSTLY 7,S             4    46   72    5   110  132    6   146  178
    4        A B,C                    4    66   92    5   118  140    6   156  198
    S        A SANDBLOW               4   210  254    5   250  254    6   250  254
    6        A Q,R,S                  4   162  188    5   184  200    6   202  220
    7        A E,F                    4    94  114    5   156  172    6   154  180
    8        A G                      4    98  118    5   160  178    6   154  172
    9        A 8,9,A                  4    60   92    5   104  128    6   180  206
    A        A E,F,G                  4    98  114    5   158  178    6   144  162
    B        B H,G                    4    64   80    5   110  124    6   170  194
    C        B I,J                    4    62   86    5   114  142    6   146  176
    D        B J,K                    4    64   94    5   126  152    6   136  158
    Z        A DIKE                   4   198  254    5   244  254    6   210  254
    E        B F                      4    52   74    5   102  116    6   168  196
    F        B QRSTOP                 4   118  196    5   160  200    6   166  218
    G        C MOSTLY P               4    72   90    5   118  136    6   158  186
    H        C S                      4    70   88    5   112  132    6   174  190
    K        C WATER                  4     4   12    5    58   76    6     0   21
    I        C Q R S T                4    66  120    5   114  150    6   168  194
    J        C J,K                    4    80   84    5   110  140    6   122  144
    W        A WATER                  4    24  116    5    84  152    6    12   92
    1        A C,D                    4    74  118    5   124  180    6   156  188
    W        A WATER                  4     0   92    5     0  146    6     0  206
    W        A WATER                  4    90  190    5   142  209    6    86  156
    D        A DIKE Z                 4     4  254    5    60  254    6     0  254
```

Figure 54. Output from BOX4.

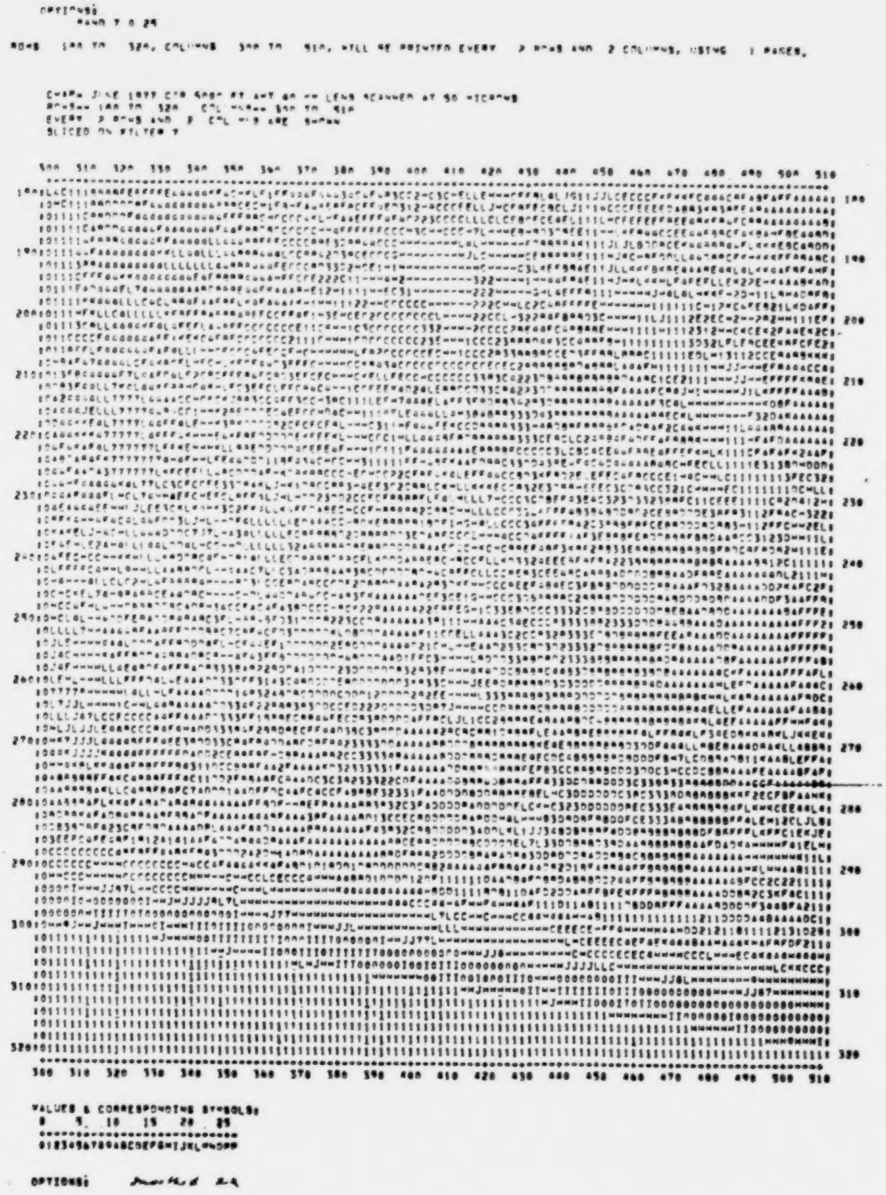


Figure 55. Portion of printed out parallelepiped classification created from program BOX4.

Reproduced from best available copy.

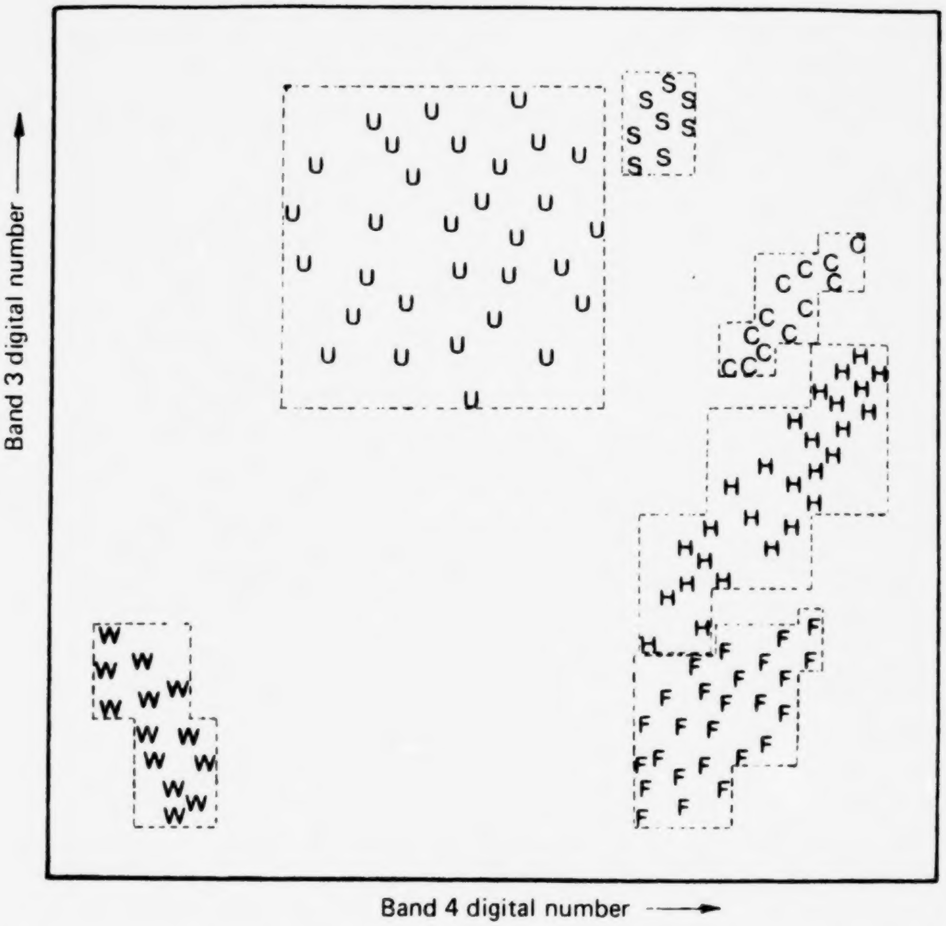


Figure 56. How a decision region can be broken into rectangles whose borders closely describe the training set distribution.

```
<MAXLIK CLASSIFICATION>: JUNE 1977 CIR 5000 FT AMT 40 MM LENS SCANNED AT 50 MICRONS

     300  320  340  360  380  400  420  440  460  480  500
      +----+----+----+----+----+----+----+----+----+----+--
  180IJ9I88F4FE4JJ4AJ F4F4394A4H99FA9IGFED D EEF4G949787F87I 180
     IHIH8C74JG44F4F8H49JA7FFG423E969E8EEFIIIFGE8F8FJ987777I
     IIIGF8GFEFJJJJ4789ACEC8GF9AH9JAII9CCAG DD8C9GFAGFGG8FCI
     II 9AGJJJJ9JJ4A4GE982CHEHHAAADAAH9DAGCIDJGA8E7EGGGFF74I
     I9HEC44J44F7CF48778EHHHAE3AEJA2CEAHJFFIID DIGHGGCI GC7I
  200I99AJJJ6JJ8F787E9F4 2AE294HEIHH9 3CJAF2H  DDIEE9I22 IEI 200
     I2H98J448FGJJAA29EHHAH999293IHE938CG9GA8   ICCHFFEE79EI
     IGAF6EJJJ8GA9GFFJ299 H9C399F99H8F243ACA477HHI2 D HF77EI
     IH84JJJJ4FA9GJ9F949JA 9EFG2GA9C2A23CA8C87778D  DD F77EI
     IF444JJ6489HA2ECF4E9C9  AA44JAAC2DC3CC48778EGII I2CG74I
  220IC48G6JJ4G4HAGFECC44FJA92HGJA8A8A83F9944FCAFAG  IGF7A7I 220
     I887GG6JJGG9JEGCGAGJ99AHI 44F8F899C3E49CG7A4AEGHIEH84CI
     I44444JJJ999F227JJ 898AE22A GJGG4829AAE99822HAAEH HI9JI
     IJEGF44J43JG492JJJFC89EFAA898I J9H9FF889C298CC343HF7 2I
     I94JD46G4CC66A3JJJ9F82CACC48AEEI994FF73AAEC878C7922C9II
  240I9499AGAJJCCJA89EEC84C9JACCE989 J32EE4472C2C879778H9I I 240
     I9JG44A2J4A8A9I29EC83C28CCC29GA9F4F449CACC8774277CCGF2I
     IH9GAJAC8C97AJ97E8899CG27773F9I998999238CCC8A77C7C77F8I
     IHJJA74878FCAE9F9C2CC98CA7CH9F 79293A8F8CCCE777C777744I
     IDEAAG48CG8C9AJ448CCC97C7CE9AAGCC3A82CACA84CC7C8777FF7I
  260IDEAADJ9CJE7CCC8324CCECCCCG39HDEC8ACCCA2ACG7F7GAFCC7A4I 260
     IDJDAAHJ G77CC3F2893C3C3CCCCJ  9C9AAAACCFAJCA4EGFC7778I
     IDGJDE493447C8FFACEF4CA2CC772928CFFG7CE83FJF4J2E7GAGGEI
     I GDDJJ4F4F7C37FFC87A298A777AC8CA3E998A843CAJ9C87C78EFI
     IF888FGFCFF4ICFC897C392939FCACACCAFG3CACF9382C9C7IFA78I
  280I7777JJFACAA47CF8F7E8F78A227CC7CCE9A92CCCE33J8F8FGGEGJI 280
     IF83A43CCC77A7C4C778777492987F2CG D2AC44CC8498FFFGF2EDI
     I9992948F48F4CC8CCC77777ACAACCAC783CCC7CC982A8A77GGGG I
     I699AAA999EAAA9AJ99448CC2I 2G 2C7848C8AC44F8A777892HHII
     INNONNNNM  JJJJ9JAAAA9AAA499444F44AIC AII8CFF87CCFGC7 I
  300I J    AA8ONBNNNNAB  JAAAAAAAAAA9A9EEE444I772IIA I G2I 300
     IKKKKKKKK     J  ANNMNAONNNNNNN  6A99A999EEJAA9J9EJ4444I
     IKK KKKK KKK K1 KK  K   J  NMMNNNB5NNNNNMB  6AAAJ6AAAAI
     IKKKKKKKKKKK KKKK KKK KKKKKK1 KK     BANANONNNNNNNNNA I
     IKKKKKKKKKKKKK KK K 1KK KKK K1KK KKK KKK KK   JJ ANNBNNI
  320IKKKKKKKKKKKKKKKKKKKKKKK  K    K 1K11K1KKKKK1KKKKKK  I 320
      +----+----+----+----+----+----+----+----+----+----+--
     300  320  340  360  380  400  420  440  460  480  500
```

Figure 57. Portion of a maximum likelihood classification of the site.

describes the variance and the correlation of each training set). Figure 58 shows probability values plotted on a three dimensional graph of a scatter diagram. The vertical axis expresses the probability of a pixel value being a member of one of the classes. This creates a bell shaped surface called a probability density function for each training set. These probability density functions are used to classify an unidentified pixel by computing the probability of that pixel's value belonging to each category. The computer evaluates this probability for each category and places the pixel in the category where it most likey belongs. A probability threshold can be set so that pixels with a low probability of belonging in any class will be put into an "unknown" category. Program MAXLIK is a maximum likelihood classifier.

A third type classifier is an elliptical classifier. This classifier relies on the statistics of each training set to classify a scene, pixel by pixel. Training set data are analyzed to determine mean vectors, eigen values, and eigen vectors, and covariance matrices. A table, compiled from statistics generated from the training sets can be used to classify the scene by comparing each pixel against the look up values (Figure 59). Program TABCLASS is an elliptical classifier. An elliptical classifier is more expensive to use than a parallelepiped classifier but less expensive than a maximum likelihood classifier if only 20 or fewer classes are used.

## Steps Taken to Generate Computer-Assisted Maps

Figure 60, 61, 62, and 63 are the results of classifying data from four scanned airphotos with a maximum likelihood classifier. Three of the four airphotos were color infrared transparencies taken 25 September 1975, 24 July 1976, and 25 July 1977. The fourth airphoto is a color transparency which was included in order to compare classification results using color and color infrared film data. All photos used for this computer-assisted mapping (scale 1:38,200) were scanned at 50 μm so that the ground resolution of each pixel was 1.9 m.

The steps taken to reach film product renditions of these four classifications were as follows: each photo was scanned using a 50 μm pixel size through a blue, green, and red filter to extract blue, green, and red film layer data. These data were corrected using programs DLOGE, CORRECT, and FALLOFF. Only the July 1976 data were not corrected for falloff.

Once the data were corrected, a 26 character density slice was run on each scene which was used to select training sets. Between 50 and 80 training sets were selected from the data in Bands 4, 5, and 6 for each airphoto classified. Training set selection took 3 to 4 h for each scene. Training sets were entered into a training set file using program TRAIN. Programs HSGRAM, SCATTER, and CLASSBAR were run on each training set file to select the "cleanest" training sets. Program MODSET was used to delete training sets which appeared too broad or scattered to be useful. At this point each training set file was copied three times. Program MODSET was used to delete all classes except those selected from one band. Thus the

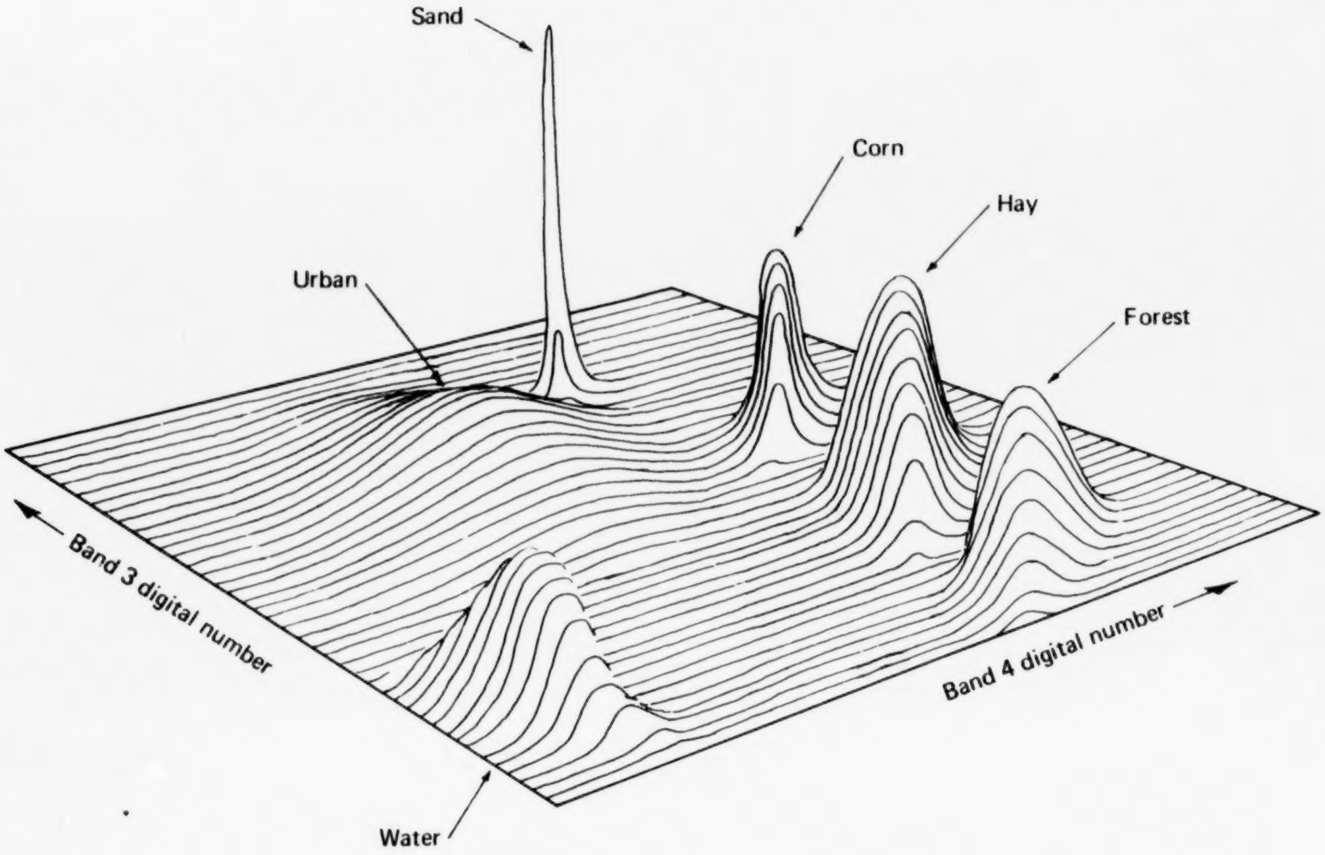
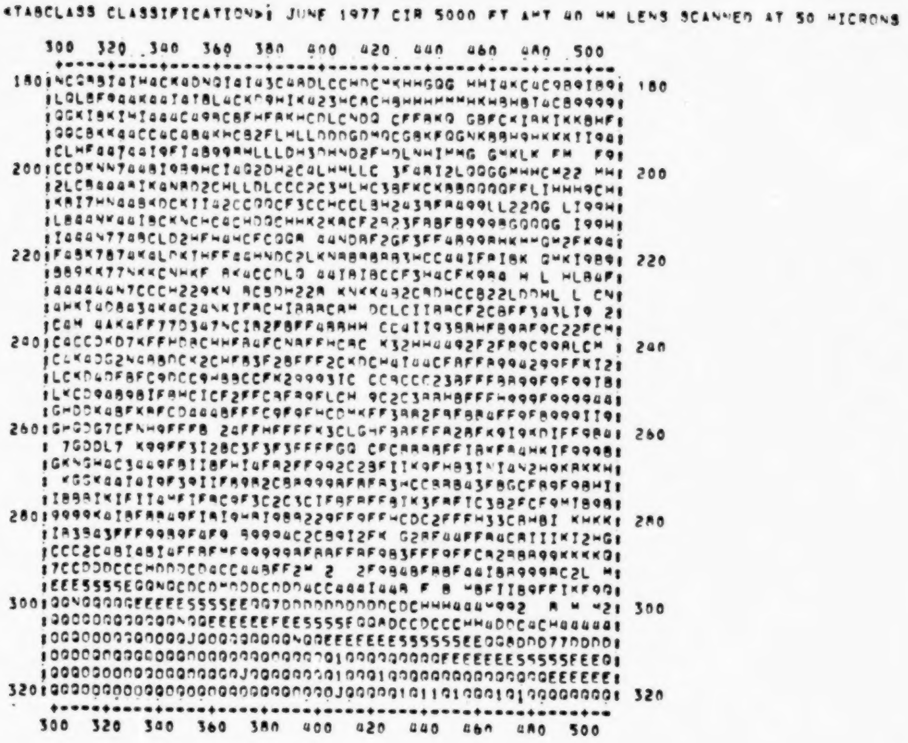


Figure 58. Probability values plotted on a three-dimensional graph of a scatter diagram (from Lillesand and Kiefer, 1979).



<TABCLASS CLASSIFICATION>; JUNE 1977 CIR 5000 FT AMT 40 MM LENS SCANNED AT 50 MICRONS

300 320 340 360 380 400 420 440 460 480 500
180
200
220
240
260
280
300
320

Figure 59. Portion of a classification of the site using program TABCLASS.

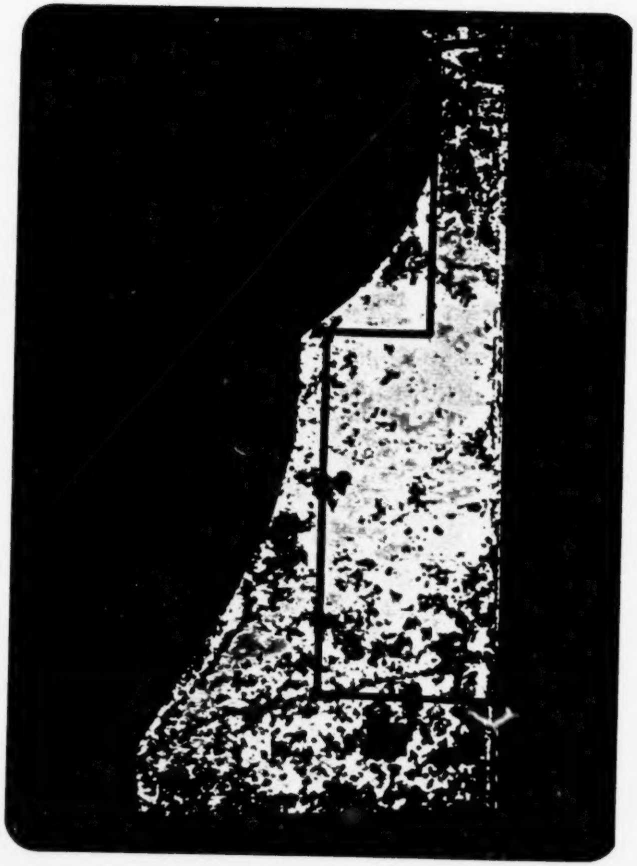


Figure 60. Computer assisted map made from CIR airphoto on September 15, 1975.

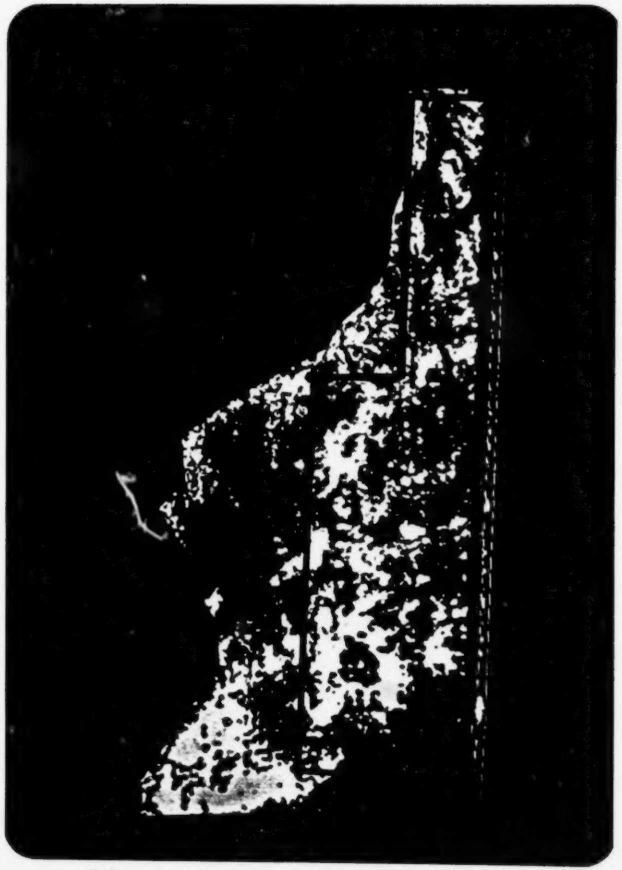


Figure 61. Computer assisted map made from CIR airphoto on July 24, 1976.

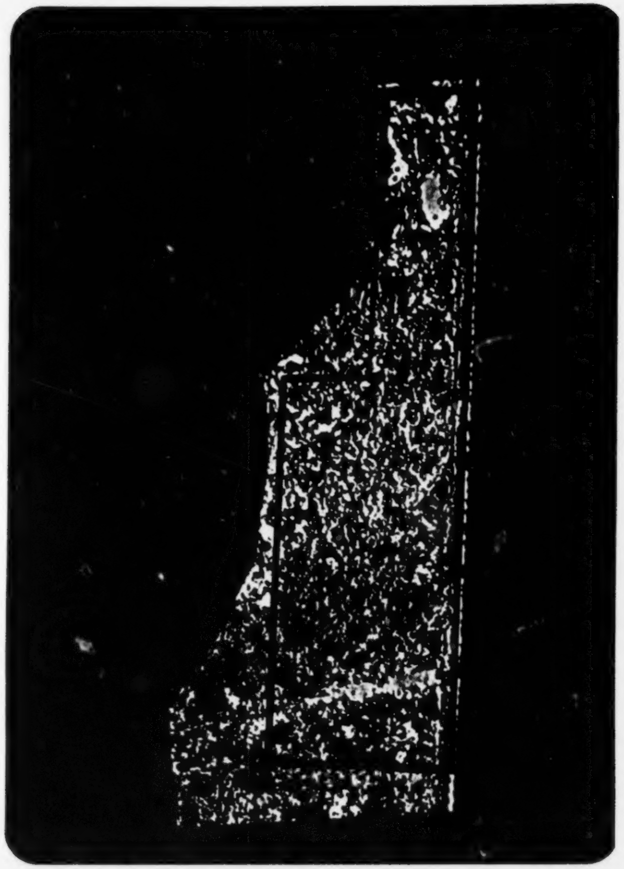


Figure 62. Computer assisted map made from CIR airphoto on June 25, 1977.

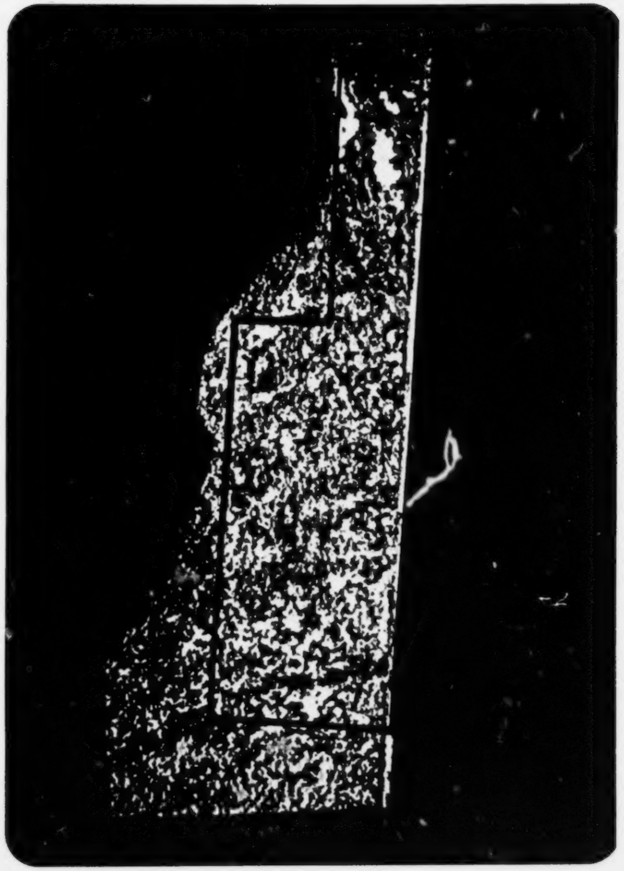


Figure 63. Computer assisted map made from color airphoto on June 25, 1977.

master file contained 81 training sets but the copied files were modified so that they contained 27 training sets from Band 4, Band 5, and Band 6, respectively. This made it possible to combine similar classes from the same band. Classes were always cleantrained once they were combined to discard any pixels beyond the 2.5 standard deviations of the mean values of the training set. Once similar classes from each band were combined, the same changes were made in the master file, and the copied files were deleted. At this point programs CLSTRN and CLASSBAR were used to combine similar classes selected from different data bands.

Once satisfactory training sets were obtained, the values could be entered into program BOX4, a parallelepiped classifier. Inexpensive to run, this classifier points out classes of marginal use. (If no pixels or very few pixels are assigned to a particular class using program BOX4, that class should be discarded before running classification programs MAXLIK or TABCLASS.) Running BOX4 also displays any unclassified areas. Training sets should be selected from any unclassified areas and put into the master training set file so these areas will be classified thereafter. These new training sets must be cleaned and displayed to see whether they will be useful or redundant. Processing training sets to use in the TABCLASS or MAXLIK classifiers took 4 to 6 h.

Using the September 1975 training sets (81 classes reduced down to 22) the analyst ran the TABCLASS and MAXLIK programs on the corrected September data. Since MAXLIK was less costly to use and provided as good a classification as TABCLASS, program MAXLIK was used for all further classification.

Next, program OUTLINE was used to outline the actual study site area within the data-file. The accuracy of delineation of this new area can be checked by running program SLICE which reveals the outline of the newly created area. Program MAXLIK was run on the outlined data-file to create a classification, followed by program SMOOTH which was run twice to make the classification more readable. The July 1976 classification, the most garbled of the four classifications, was smoothed three times. The next step was to run program SLICE specifying the number of classes to be displayed and the symbol to be assigned to each class. Several vegetation classes had more than one spectral response pattern. Each of these patterns was assigned the same symbol, reducing the 22 to 24 classes entered to the eight to 10 classes which can be identified on the classifications.

Once the classification was labelled as appropriately as possible, program MAXLIK was run on the corrected outline data-file at resolution 1, putting the classification into a file without making a printout. The classification was subsequently repeated the appropriate number of times. Next, using program COLOR, selected color values were assigned to each class, giving classes which defined the same resource the same color. Lastly the analyst ran program FILM70 which writes these color values onto computer tape such that the scanning microdensitometer can read and convert them to film densities, band by band, which are written directly onto film. The resulting three color separation film chips (blue, green, and red) were put into the appropriate separation and combined onto a viewing screen. Figures 60 to 63 are photos of the color composites of each classification created in this manner.

## Computer-Assisted Mapping Results

Figure 60 to 63, color renditions of the four computer-assisted classifications, display approximately the same ground area. Both the MAXLIK and TABCLASS programs make it possible to select and enter an on-the-ground area of pixel size and from this calculate the total area classified as each vegetation class. On-the-ground pixel size was 3.6 $m^2$ for each of the four classifications in this study.

Since the areas considered in each classification were only approximately the same, the analyst returned to the original four data-files and used program OUTLINE to outline an exact polygon (shown by the black outlines in Figures 60 to 63). Total areas of each vegetation class with time were compared to demonstrate change with time.

Table 25 lists area (in $m^2$) and percent cover of the vegetation classes which could be identified on each classification. (Not all classes could be identified on all classifications.) The number of classes identified on each scene is a function of: 1) which classes could be photointerpreted by the analyst and 2) which classes could be defined using this method. (If the analyst had selectively targeted the various communities, the number of vegetation classes delineated using this method would be greater and more consistent.)

Table 25 shows the area in $m^2$ for each vegetation class for the September 1975 classification, the July 1976 classification and the two June 1977 classifications. Total area classified/scene is about 246,000 $m^2$ (68,000 pixels).

On the September 1975 classification, eight vegetation classes could be identified (Table 25) while on the July 1976 classification only six vegetation classes could be identified. Seven vegetation classes were identified on the June 1977 CIR classification; six vegetation classes were identified on the June 1977 color classification.

Table 26 lists the agglomerated classes used to summarize computer-assisted mapping results. The *Carex lacustris* and *Carex stricta* classes were combined into a Sedges class. The Spiraea/Sedges and Shrubs classes were combined. Transition and Emergents classes were combined into a Transition-Emergents class. The Other Disturbance class subsumes the *Lemna minor* and Weedy Annuals classes. For 1975 no Degraded Sedges area could be identified using computer-assisted mapping; on the June 1977 CIR classification, no Sedges could be identified. Table 27 lists the color assigned to each vegetation class using program COLOR throughout the four classifications.

TABLE 26. VEGETATION CLASSES USED TO SUMMARIZE COMPUTER ASSISTED MAPPING

| Vegetation Classes | 25 September 1975 | 24 July 1976 | 25 June 1977 CIR | 25 June 1977 COLOR |
|---|---|---|---|---|
| Shrubs | 9.7 | 4.4 | 6.7 | 7.6 |
| *Spiraea*/Sedges | 18 | 13 | 9.6 | 17 |
| Open Water | 0.5 | 5.7 | 8.1 | 6.1 |
| Transition-Emergents | 22 | 29 | 17 | 20 |
| Sedges | 39 | 18 | 13 | - |
| Degraded Sedges | - | 15 | 21 | 24 |
| Other Disturbance | 1.8 | 10 | 18 | 20 |
| Dike | 6.2 | 3.5 | 1.9 | 4.8 |
| Unclassified | 2.8 | 0.4 | 3.9 | 1.2 |

TABLE 27. COLOR AND EXPOSURE VALUES ASSIGNED TO VEGETATION CLASSES IDENTIFIED USING COMPUTER ASSISTED MAPPING

| Vegetation class | Color assigned | Exposure values<br>Blue | <br>Green | <br>Red |
|---|---|---|---|---|
| *Carex lacustris* | Orange | 0 | 235 | 255 |
| *Carex stricta* | Red | 0 | 0 | 255 |
| *Spiraea* | Dark magenta | 200 | 0 | 200 |
| Transition | Light green | 0 | 255 | 0 |
| Emergents | Dark green | 0 | 190 | 0 |
| Dike | Olive | 120 | 190 | 0 |
| Shrubs | Brown | 0 | 190 | 230 |
| *Lemna minor* | Yellow | 0 | 255 | 255 |
| Open water | Dark blue | 190 | 0 | 0 |
| Transition-Emergents | Medium green | 0 | 223 | 0 |
| Weedy Annuals/Floating Mat | Cyan | 225 | 225 | 0 |
| Degraded Sedges | Reddish brown | 0 | 190 | 255 |
| *Spiraea*/Sedges | Magenta | 255 | 0 | 255 |

In the analyst's opinion, the September 1975 and June 1977 CIR classifications are the most accurate of the four classifications. The greatest number of vegetation classes were identified on these two scenes when they were photointerpreted in conjunction with field data.

From field studies, the analyst knew that sedges were the predominant species at the study site in 1975. The Sedges category includes the *Carex lacustris, Carex stricta,* and *Spiraea*/Sedges classes. By 1977 sedges, particulary *Carex lacustris*, had largely disappeared while large areas of open water showed in places where previously there had been none. Much of the Transition class had been destroyed by 1977 and large areas of Open Water, Weedy Annuals and *Lemna minor* were appearing in its place.

In September 1975, the areas classified *Carex stricta, Carex lacustris*, and *Spiraea*/Sedges covered 143,000 $m^2$ or 57% of the total area. By June 1977 the area classified as *Carex stricta* and *Spiraea*/Sedges (*Carex lacustris* could no longer be identified) had dropped to 57,000 $m^2$ or 23% of the total area. Shrub area declined slightly. Combined area classified as Transition and Emergents in 1975 came to 54,000 $m^2$ or 22% of the total area. By June 1977, although water levels were higher, encouraging growth of this type of vegetation, Transition-Emergent area had shrunk to 42,000 $m^2$ (17% of the total area). *Lemna* area increased from 1.8% (4,500 $m^2$) to 12% (29,000 $m^2$) from 1974 to 1977. Area classified as Weedy Annuals increased from zero in 1975 to 5.9% or 14,000 $m^2$ in 1977. Total area classified as disturbance increased by 45% over the 21 months between September 1975 and June 1977. Table 25 shows the amount of open water increasing by a factor of 18 or 13 (depending on whether June 1977 CIR or June 1977 color estimates are used), from 1,100 $m^2$ to 20,000 $m^2$ or 15,000 $m^2$.

The July 1976 CIR classification results are not as good as those of September 1975 and June 1977 CIR for the following reasons. All the red tones in this airphoto are very saturated, meaning that most of the vegetation was vigorous and strongly reflecting infrared energy. While these red tones offer the advantage of being consistent across the scene (Meyer 1977), they are difficult to distinguish one from another. Training set values in the blue data band were very broad for almost all training classes. The analyst suspects the blue band data were not helpful in doing this classification. Lastly the analyst did not correct this July 1976 data for lens falloff. This may explain why the southern end of the study site was adequately classified even before smoothing the data while the northern end's data seemed badly garbled, even after smoothing. This caused fewer classes to be defined, for many classes had to be combined into one class to make any sense out of the classification results.

Classification results for the June 1977 color photo were less satisfactory than results from the September 1975 and June 1977 color classifications but for different reasons. In this case the data were corrected for lens falloff so the poorer classification results can be attributed to the data being scanned from a color airphoto. On any color photo it is more difficult to distinguish the various greens of the study site wetland vegetation classes than to distinguish these same classes on a color infrared airphoto. Water appears as a muddy green and is difficult to differentiate from the surrounding vegetation. Consequently the analyst has least confidence in the accuracy of this classification done from color film data of any of the four classifications.

Computer-assisted mapping as a method will be greatly improved when a minicomputer, loaded with all the programs needed to do this mapping, is available and connected to a color terminal. This will allow film exposure data to be displayed on a terminal screen. Training sets can be selected from the data and outlined and entered in the program TRAIN file by using a cursor to outline them. This will greatly speed up this process.

A terminal screen display will also be invaluable for viewing a classification in order to correctly label classes with appropriate symbols or colors. The great advantage of the color display will be: 1) its lack of distortion of the scene (which occurs with a computer printout) and 2) its color capability for differentiating classes. Using a terminal screen display will allow the analyst to sit with a color print of the scanned photo in hand and match the patterns on the photo with those on the display screen.

A strong point of computer-assisted mapping is its ability to consistently classify a scene. Error can be introduced, however, when 1) the analyst combines training sets (in order to have an adequate number of pixels from which to derive satisfactory defining statistics) and 2) when the analyst combines classes in an effort to make them meaningful. If the training sets cannot be identified when they are selected, the analyst hopes to identify correctly the pixels which were classified using those training statistics. The analyst must assign the same symbol to those classes which are the same resource.

## Computer-Assisted Mapping Summary

Computer-assisted mapping offers consistent classification of vegetation classes and quantification of the area of each class. In addition this method offers the most readable visual product in the form of computer printed maps or color photo maps.

Considerable expertise is needed to use this method. An analyst should expect to have 60 to 80 h experience with its programs before turning out a classification in 20 to 30 h. As the computer-assisted mapping system now exists, the analyst should have experience in magnetic tape and mass storage file manipulation.

Computer-assisted maps are costly to generate and moderately time intensive. Because computer-assisted mapping involves so many steps where there is room for variation in results, the reliability (repeatability) of this method may not be great. Lastly, use of this method requires considerable training and experience.

The advantages of this method as it exists now are 1) it consistently classifies across an entire scene so that while the identity of a particular class may not be known, it is known that most of the class is being classified; 2) it quantifies the area mapped for each class in units of the analyst's choice; and 3) it generates color photo maps of the classified scene which are the most immediately readable products generated by any of the mapping methods.

# SECTION 5

# RESULTS

To evaluate the nine methods discussed in this study, it is necessary to consider 1) the kind of information each provides, 2) the training needed to use the method, 3) capital equipment and material costs, 4) time requirements of each method; 5) total costs incurred using each method and 6) the sensitivity and reliability of each method. Only then do the advantages and disadvantages of using each method become clear.

Tables 28-41 were assembled in the process of evaluating these methods. They should be referred to throughout the discussion. Table 28 catalogs the vegetation classes identified with each of the eight classification methods. Table 29 lists the expertise needed to use each method (botanical-ecological knowledge, computer experience, computer-assisted image interpretation skill, visual airphoto interpretation skill, and drafting skill). Table 30 enumerates capital equipment costs for data collection. Table 31 lists data collection materials costs for one data set. Table 32 catalogs the capital equipment used with the nine methods. Table 33 lists capital equipment costs for data analysis. Table 34 lists data processing material cost for one data set. Table 35 summarizes the data collection and analysis time requirements of each method while Table 36 lists total time to collect and analyze one set of data using each of the nine methods. Table 37 gives a breakdown of data collection, processing and labor costs for each method when used in a 172 ha area. Table 38 lists data collection, data processing and labor cost/method for one data set and four data sets in a 172 ha area. Table 39 rates each method's efficiency on the basis of time and cost required to use the method. Table 40 evaluates method sensitivity based on the number of vegetation classes defined and data type. Table 41 evaluates method reliability in terms of data collection method, data analyst interaction and quantitative or qualitative results.

This chapter continues with a discussion of method efficiency, sensitivity and reliability. This is followed by an evaluation of each method in terms of time and cost to use the method and the method's sensitivity and reliability. (All costs quoted in sections 31, 32, and 33 are costs using the in-house capability at the University of Wisconsin-Madison.) If a user went to the private sector to contract to have the methods discussed in this study used, the costs would be two to three times the costs quoted here (Evans 1979). The six questions raised in this study's introduction are addressed and recommendations are made as to combinations of methods to use in various situations. Lastly, suggestions are made on ways to improve the present study.

TABLE 28. VEGETATION CLASSES IDENTIFIED USING THE EIGHT CLASSIFICATION AND MAPPING METHODS[a]

| Vegetation classes | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| *Carex stricta* | X | X | | | | X | X | X |
| Degraded *Carex stricta* | X | X | | | | X | X | |
| *Carex lacustris* | X | X | | | | X | X | X |
| Degraded *Carex lacustris* | X | | | | | X | X | |
| Transition | X | X | | | | X | X | X |
| Degraded transition | X | X | | | | X | X | |
| Emergents | X | X | | | | X | X | X |
| Degraded emergents | X | | | | | X | X | |
| *Spiraea alba* | X | X | | | | X | X | X |
| Shrubs | X | X | X | X | | | | |
| Open water | X | X | X | X | X | X | X | X |
| Open-emergents | | X | | | | | | |
| Weedy annuals | X | X | | X | | X | X | X |
| Transition-emergents | | | | X | | | | |
| Sedges and grasses | | | | | | X | X | |
| Grasslike | | | X | | | | | |
| Tall-coarse | | | X | | | | | |
| Grasslike-tall | | | X | | | | | |
| Disturbed vegetation | | | | | X | | | |
| Undisturbed vegetation | | | | | X | | | |
| Degraded sedges | | | | X | | X | | X |
| Shrubs and trees | | | | X | | X | | |
| *Typha latifolia* | | | | | | X | X | |
| *Scirpus fluviatilis* | | | | | | X | X | |
| Floating mat | | | | | | X | X | |
| *Lemna minor* | | | | X | | X | X | X |
| Trees | | | | X | | X | X | |
| *Spiraea*/sedges | | | | | | | | X |
| *Spiraea*/shrubs | | | | | | | | X |

[a] Mapping methods are A = Diversity index; B = Subjective classification; C = Association analysis; D = Vegetation structure analysis; E = Airphoto monitoring; F = Disturbance mapping; G = Airphoto interpreted; H = Computer assisted mapping.

TABLE 29. EXPERTISE NEEDED TO USE EACH METHOD[a]

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Ground Sampling Data | | | | | | | | |
| Diversity index | X | | | | | | | |
| Subjective classification | X | | | | | | | |
| Association analysis | X | | X | | | | | |
| Structure analysis | X | | | | | | | |
| Airphoto Data | | | | | | | | |
| Airphoto monitoring | X | | | | | X | | |
| Disturbance mapping | X | | | | | X | X | |
| Airphoto-Ground Sampling Data | | | | | | | | |
| Airphoto grid analysis | X | | | | | X | | |
| Vegetation mapping | X | | X | | | X | X | |
| Computer Assisted Mapping | X | | X | | X | X | | |

[a] Mapping methods are A = Diversity index; B = Subjective classification; C = Association analysis; D = Vegetation structure analysis; E = Airphoto monitoring; F = Disturbance mapping; G = Airphoto interpreted; H = Computer assisted mapping.

TABLE 30. CAPITAL EQUIPMENT COSTS FOR PHOTOGRAPHIC DATA COLLECTION[a]

| Data type | Equipment used | Cost, $ |
|---|---|---|
| Airphoto data | Hasselblad 500 EL/M chrome body | 1620 x 2 = 3420 |
| | 40 mm Distagon lens | 2550 x 2 = 5100 |
| | A70 Film magazine | 615 x 2 = 1230 |
| | Daylight filter | 249 x 1 = 250 |
| | Minus blue filter | 249 x 1 = 250 |
| | Filter holder | 120 x 2 = 240 |
| | Camera mount | 300 x 1 = 300 |
| | | 10,790 |

[a] Costs quoted in April, 1979.

## TABLE 31. DATA COLLECTION MATERIALS COST FOR ONE DATA SET

| Data type | Materials used | Total cost, % |
|---|---|---|
| Ground sampling data | Data sheets 140 x \$0.02 = | 2.80 |
| | Transportation \$0.10/mile x 80 miles x 2 days | 16.00 |
| | 0.25 $m^2$ Circular quadrat \$0.20 x 2 = | .40 |
| | 62 metal stakes @ \$2.55 x 62 = | 158.10 |
| | | 177.30 |
| Airphoto data | Airplane & photographer \$150/hr x 1 = | 150 |
| | Film-two 15 ft rolls \$2.50/ft x 30 ft = | 75 |
| | Film processing \$1.00/ft x 30 ft = | 30 |
| | Film mailing--UPS 2 lb package, roundtrip | 16 |
| | | \$271 |

## TABLE 32. CAPITAL EQUIPMENT USED WITH THE NINE METHODS

| Method | Capital equipment |
|---|---|
| 1. Diversity index | None |
| 2. Subjective classification | Computing capability |
| 3. Association analysis | Computing capability |
| 4. Vegetation structure analysis | None |
| 5. Airphoto monitoring | Stereoscope and light table<br>Camera equipment |
| 6. Disturbance mapping | Color additive viewer<br>Camera equipment |
| 7. Airphoto grid analysis | Stereoscope and light table<br>Computing capability |
| 8. Airphoto interpreted vegetation mapping | Color additive viewer<br>Computing capability<br>Camera equipment |
| 9. Computer-assisted mapping | Scanning microdensitometer<br>Computing capabilities<br>Camera equipment |

## TABLE 33. CAPITAL EQUIPMENT COSTS FOR DATA ANALYSIS[a]

| Items | Cost, \$ |
|---|---|
| Stereoscope and light table | 12,000 |
| Color additive viewer | 16,000 |
| Scanning microdensitometer | 100,000 |
| Computing capability | |

[a] Costs quoted in April, 1979.

TABLE 34. DATA PROCESSING MATERIAL COST FOR ONE DATA SET

| Data type | Method | Materials | Cost, $ |
|---|---|---|---|
| Ground sampling data | Diversity Index | None | |
| | Subjective classification | Data printout | 27 |
| | Association analysis | Total run cost | 27 |
| | Structure analysis | Data printout | 27 |
| Airphoto data | Airphoto interpretative monitoring | 1 airphoto | 2.66 |
| | Disturbance mapping | 1 airphoto | 2.66 |
| | | Mylar @ $.10/in. x 15" | 1.50 |
| Airphoto and ground data | Airphoto grid analysis | 1 airphoto | 2.66 |
| | | Grid to scale | 3.75 |
| | | Sampling station location map | 3.75 |
| | Vegetation mapping | Mylar @ $.10 in. x 15" | 1.80 |
| | | Airphoto | 2.66 |
| | | Sampling station location map | 3.75 |
| | Computer-Assisted mapping | 12" computer tape | 6.00 |
| | | Tape of scanned image | 20[a] |
| | | Airphoto | 2.66 |
| | | Computer processing time charge | 40 |

[a] If airphoto scanned at UW-Madison. The charge is $35/h.

TABLE 35. TIME (h) FOR DATA COLLECTION AND ANALYSIS FOR A 33.5 HA SITE

| Method | Hours to collect data | First data analysis set up time | Subsequent data analysis time | First data processing time | Subsequent data processing time | Total time per method |
|---|---|---|---|---|---|---|
| 1. Diversity index | 16 | 4 | 4 | 6 to 8 | 1 | 21 |
| 2. Subjective classification | 32 | 12 | 6 | 6 | 4 | 42 |
| 3. Association analysis | 16 | 14 to 16 | 6 | 6 | 2 | 24 |
| 4. Structure analysis | 16 | 6 | 4 | 2 | 1.5 | 21 |
| 5. Airphoto interpretive monitoring | 4 | 1 | 0.25 | 1 | 0.5 | 4.7 |
| 6. Disturbance mapping | 4 | 2 | 1.2 | 1.5 to 3 | 1.2 to 3.5 | 6.5 to 8.7 |
| 7. Airphoto grid analysis | 36 | 14 | 7 | 9 | 7 | 50 |
| 8. Vegetation mapping | 36 | 18 | 10 | 11 to 13 | 7 to 11 | 54 to 57 |
| 9. Computer-assisted mapping | 2 | 4 | 2 | 4 | 16 | 22 |

TABLE 36. TIME (h) FOR COLLECTION AND ANALYSIS FOR ONE DATA SET USING EACH OF THE NINE METHODS

| Method | Total time/method | Total time rating |
|---|---|---|
| 1. Diversity index | 21 | Medium |
| 2. Subjective classification | 42 | High |
| 3. Association analysis | 24 | Medium |
| 4. Structure analysis | 21 | Medium |
| 5. Airphoto interpretive monitoring | 4.8 | Low |
| 6. Disturbance mapping | 6.5 to 8.8 | Low |
| 7. Airphoto grid analysis | 50[a] | High |
| 8. Airphoto interpreted vegetation mapping | 54 to 57[b] | High |
| 9. Computer-assisted mapping | 22 | Medium |

[a] Total time for airphoto grid analysis if association analysis were used to analyze the ground data would be 32 h.

[b] Total time for airphoto interpreted vegetation mapping if association analysis were used to analyze the ground data would be 36 to 39 h.

| | | |
|---|---|---|
| Low time requirement | is | 4.8 to 8.8 h |
| Medium time requirement | is | 21 to 24 h |
| High time requirement | is | 42 to 57 h |

## TABLE 37. A BREAKDOWN OF DATA COLLECTION AND PROCESSING COSTS AND LABOR COSTS FOR ONE SET AND FOUR SETS OF DATA FROM A 33.5 HECTARE STUDY SITE

| | Time (h) | Cost/h ($) | Cost/data set ($) | Cost/4 data sets ($) |
|---|---|---|---|---|
| **Diversity index** | | | | |
| Data collection--materials | | | 178 | 238 |
| Data collection--labor | 8 | 13 | 104 | 416 |
| | 8 | 3.5 | 28 | 112 |
| | | | 310 | 766 |
| 1st set up time | 4 | 13 | 52 | 52 |
| 1st data processing time | 7 | 13 | 91 | 91 |
| | | | 143 | 143 |
| 2nd set up time each | 4 | 13 | | 156 |
| 2nd data processing time each | 1 | 13 | | 39 |
| | | | — | 195 |
| Total Cost | | | 453* | 1,104** |
| **Subjective Classification** | | | | |
| Data collection--materials | | | 178 | 238 |
| Data collection--labor | 16 | 13 | 208 | 832 |
| | 16 | 3.5 | 56 | 224 |
| Data processing materials | | | 27 | 108 |
| | | | 469 | 1,402 |
| 1st set up time | 12 | 13 | 156 | 156 |
| 1st data processing time | 6 | 13 | 78 | 78 |
| | | | 234 | 234 |
| 2nd set up time each | 6 | 13 | | 234 |
| 2nd data processing time each | 4 | 13 | — | 156 |
| Total Cost | | | 703* | 2,026** |
| **Association analysis** | | | | |
| Data collection--materials | | | 178 | 238 |
| Data collection--labor | 8 | 13 | 104 | 416 |
| | 8 | 3.5 | 28 | 112 |
| Data processing materials | | | 31 | 125 |
| | | | 341 | 891 |
| 1st set up time | 15 | 13 | 195 | 195 |
| 1st data processing time | 6 | 13 | 78 | 78 |
| | | | 273 | 273 |
| 2nd set up time each | 6 | 13 | | 234 |
| 2nd data processing time each | 2 | 13 | — | 78 |
| Total Cost | | | 614* | 1,475** |

Table 37. (Continued)

| | Time (h) | Cost/h ($) | Cost/data set ($) | Cost/4 data sets ($) |
|---|---|---|---|---|
| Structure Analysis | | | | |
| Data collection--materials | | | 178 | 238 |
| Data collection--labor | 8 | 13 | 104 | 416 |
| | 8 | 3.5 | 28 | 112 |
| Data processing materials | | | 27 | 108 |
| | | | 337 | 874 |
| 1st set up time | 6 | 13 | 78 | 78 |
| 1st data processing time | 2 | 13 | 26 | 26 |
| | | | 104 | 104 |
| 2nd set up time each | 4 | 13 | | 156 |
| 2nd data processing time each | 1.5 | 13 | — | 60 |
| | | | | 216 |
| Total cost | | | 441* | 1,192** |
| Airphoto Monitoring | | | | |
| Data collection--materials | | | 271 | 1,084 |
| Data collection--labor | 4 | 13 | 52 | 208 |
| Data analysis materials | | | 3 | 11 |
| 1st data set up time | 1 | 13 | 13 | 13 |
| 1st data processing time | 1 | 13 | 13 | 13 |
| 2nd data set up time each | 0.25 | 13 | | 10 |
| 2nd data processing time each | 0.50 | 13 | — | 19 |
| Total Cost | | | 352* | 1,357** |
| Airphoto Disturbance Maps | | | | |
| Data collection--materials | | | 271 | 1,084 |
| Data collection--labor | 2 | 13 | 52 | 208 |
| Data analysis materials | | | 4 | 17 |
| 1st data set up time | 2 | 13 | 26 | 26 |
| 1st data processing time | 3.5 | 13 | 45 | 45 |
| 2nd data set up time each | 1 | 13 | | 39 |
| 2nd data processing time each | 2 | 13 | — | 78 |
| Total cost | | | 398* | 1,497** |
| Airphoto Grid Analysis | | | | |
| Data collection--materials | | | 271 | 1,084 |
| Data collection--labor | 2 | 13 | 26 | 104 |
| Data processing materials | | | 8 | 32 |
| | | | 305 | 1,220 |
| 1st data set up time | 2 | 13 | 26 | 26 |
| 1st data processing time | 3 | 13 | 39 | 39 |
| | | | 65 | 65 |

Table 37. (Continued)

| | Time (h) | Cost/h ($) | Cost/data set ($) | Cost/4 data sets ($) |
|---|---|---|---|---|
| 2nd data set up time each | 1 | 13 | | 39 |
| 2nd data processing time each | 2 | 13 | | 78 |
| Grid Analysis | | | 370 | 1,402 |
| Subjective Classification | | | 703 | 2,026 |
| Total | | | 1,073* | 3,428** |
| Vegetation Mapping | | | | |
| Data collection--materials | | | 271 | 1,084 |
| Data collection--labor | 2 | 13 | 26 | 104 |
| Data processing materials | | | 10 | 41 |
| | | | 307 | 1,229 |
| 1st data set up time | 6 | 13 | 78 | 78 |
| 1st data processing time | 7 | 13 | 91 | 91 |
| | | | 169 | 169 |
| 2nd data set up time each | 3.75 | 13 | | 146 |
| 2nd data processing time each | 5 | 13 | | 195 |
| Vegetation Mapping | | | 476 | 1,739 |
| Subjective Classification | | | 703 | 2,026 |
| Total | | | 1,179* | 3,765** |
| Computer-assisted mapping | | | | |
| Data collection--materials | | | 271 | 1,084 |
| Data collection--labor | 2 | 13 | 26 | 104 |
| Data processing materials | | | 79 | 317 |
| 1st data set up time | 4 | 13 | 52 | 52 |
| 1st data processing time | 40 | 13 | 520 | 520 |
| 2nd data analysis set up cost | 2 | 13 | | 78 |
| 2nd data processing time | 20 | 13 | | 780 |
| | | | 948* | 2,935** |

*Cost for first data set.

**Cost for first data set plus three subsequent sets.

### TABLE 38. DATA COLLECTION AND PROCESSING AND LABOR COSTS FOR ONE DATA SET AND FOUR DATA SETS FROM A 33.5 HA SITE

| | Total cost 1 year's data | Total cost from years 1, 2, 3[a] | Total cost Rating |
|---|---|---|---|
| 1. Diversity index | 217 | 1,104 | Low |
| 2. Subjective classification | 441 | 2,026 | Medium |
| 3. Association analysis | 287.15 | 1,475 | Low |
| 4. Structure analysis | 250.50 | 1,192 | Low |
| 5. Airphoto monitoring | 335.41 | 1,357 | Low |
| 6. Disturbance mapping | 366.16 | 1,497 | Low |
| 7. Airphoto grid analysis | 785.21 | 3,428[b] | High |
| 8. Vegetation mapping | 861.91 | 3,764[c] | High |
| 9. Computer-assisted mapping | 662.30 | 2,935 | High |

[a] This figure is arrived at from the costs totals for 4 yr of data found in Table 37.

[b] This figure was arrived at using subjective classification for the ground data analysis. If association analyses were used to do the ground data analysis, airphoto grid analysis cost for 1 yr of data would be $625 and for 4 yr of data would be $2,327.

[c] This figure was arrived at using subjective classification for the ground data analysis. If association analyses were used to do the ground data analyses, airphoto interpreted vegetation mapping would cost $712 for 1 yr of data and $2,663 for 4 yr of data.

[d] If these methods are contracted out with commercial firms, they will cost 2 to 3 times the amounts listed in this table.

### TABLE 39. COMBINED TIME-COST (EFFICIENCY) RATING FOR EACH METHOD

| Method | Time rating | Cost rating | Combined rating |
|---|---|---|---|
| 1. Diversity index | Medium | Low | Medium-low |
| 2. Subjective classification | High | Medium | High-medium |
| 3. Association analysis | Medium | Low | Medium-low |
| 4. Structure analysis | Medium | Low | Medium-low |
| 5. Airphoto monitoring | Low | Low | Low-low |
| 6. Disturbance mapping | Low | Low | Low-low |
| 7. Airphoto grid analysis | High | High | High-high |
| 8. Airphoto interpreted vegetation mapping | High | High | High-high |
| 9. Computer-assisted mapping | Medium | High | Medium-high |

## TABLE 40. METHOD SENSITIVITY RATING BASED ON VEGETATION CLASSES AND DATA TYPE

| | Method | Classes defined | Data type | Sensitivity rating |
|---|---|---|---|---|
| 1. | Diversity index | -- | Medium | [a] |
| 2. | Subjective classification | High | High | High-high |
| 3. | Association analysis | Medium | Medium | Medium-high |
| 4. | Structure analysis | Low | Medium | Medium-low |
| 5. | Airphoto monitoring | Medium | Low | Medium-low |
| 6. | Disturbance mapping | Low | Low | Low-low |
| 7. | Airphoto grid analysis | High | Low | High-low |
| 8. | Airphoto interpreted vegetation mapping | High | Low | High-low |
| 9. | Computer-assisted mapping | Medium | Low | Medium-low |

Vegetation classes defined--High 12-19 classes defined
Medium 8-11 classes defined
Low 3-5 classes defined

Data type--High Species stem counts data
Medium Presence-absence data
Low Airphoto data

[a] The diversity index cannot be rated as it could not be assigned a vegetation classes defined rating.

TABLE 41. METHOD RELIABILITY BASED ON DATA COLLECTION REPEATABILITY DATA-ANALYST INTERACTION, AND QUANTITATIVE OR QUALITATIVE RESULTS

| Method | Data collection repeatability | Subjective data analyst interactions | Quantitative or qualitative results |
|---|---|---|---|
| 1. Diversity index | Medium | High | Medium |
| 2. Subjective classification | Low | Medium | Medium |
| 3. Association analysis | Medium | High | High |
| 4. Structure analysis | Low | Medium | Medium |
| 5. Airphoto monitoring | High | Low | Low |
| 6. Disturbance mapping | High | Low | Low |
| 7. Airphoto grid analysis | High | Low | Medium |
| 8. Airphoto interpreted vegetation mapping | High | Low | Medium |
| 9. Computer-assisted mapping | High | Low | High |

Data collection repeatability--High airphoto data
Medium presence-absence data
Low species stem counts data

Data analyst interaction--High--Minimum subjective data-analyst interaction
Medium--Medium subjective data-analyst interaction
Low--Maximum subjective data-analyst interaction

Quantitative or qualitative results--High--Computer quantitative results
Medium--Analyst quantitative results
Low--Analyst qualitative results

## METHOD EFFICIENCY

For purposes of this study, an efficient method is defined as one requiring little time and little cost to use. Table 36 lists the total time in hours to use each method. Airphoto interpreted monitoring and disturbance mapping had the lowest time requirement. The diversity index, association analysis, structure analysis, and computer-assisted mapping were all rated as medium time intensive methods, taking between 21 and 24 h to use. Subjective classification, airphoto grid analysis and airphoto interpreted vegetation mapping were the most time intensive methods, taking between 42 and 57 h to use. Indeed, it is interesting to note that there is a tenfold difference between the least and most time intensive methods.

Table 37 breaks each method's total cost into: 1) data collection equipment cost, 2) data collection materials cost, 3) data collection labor cost, 4) first time data analysis set up cost, 5) first time data processing cost and subsequent data analysis set up cost, and 6) subsequent data processing cost. Total Cost 1 for one data set reflects the greater labor cost incurred the first time a method is used. Total Cost 2 for one data set reflects the reduced labor cost required once the analyst is familiar with the method. Cost per four data sets is made up of the cost of one data set at Total Cost 1 plus three data sets at Total Cost 2.

Table 38 uses figures from Table 37 to present a data collection, processing and labor cost rating for each of the nine methods. The diversity index, association analysis, structure analysis, airphoto monitoring and disturbance mapping are low cost methods ranging from \$217/data set to \$366/data set. Subjective classification is rated as a medium cost method (costing \$441.00) while airphoto grid analysis, vegetation mapping and computer-assisted mapping are rated as high cost methods (ranging from \$662 to \$862). The cost difference among these methods is less dramatic than the time difference. There is only a four-fold difference between the most and least costly methods.

Table 39, a combined time-cost (efficiency) rating table, was assembled from information presented in Table 36 and 38. The method with the greatest efficiency is a low cost method requiring little time to use. The method with the least efficiency would have a high time requirement and a high cost rating.

The most efficient of the nine methods are airphoto monitoring and disturbance mapping. The diversity index, association analysis and structure analysis have a medium to high efficiency. Subjective classification and computer-assisted mapping have a combined medium-high rating indicating their medium to low efficiency. Airphoto grid analysis and airphoto interpreted vegetation mapping were rated as high time and high cost methods, indicating they are the least efficient of the nine methods.

## METHOD SENSITIVITY AND RELIABILITY

A method sensitivity rating table and a method reliability rating table (Tables 40 and 41) were assembled to provide ratings of all methods. Each method was evaluated for sensitivity and reliability. The analyst would prefer to evaluate each method in terms of accuracy, however, since no detailed vegetation map of the study site was made prior to its disturbance, there is no "truth" with which to compare the results of each method.

By sensitivity, the analyst means nuances of vegetation change which each method is capable of showing. Reliability refers to the repeatability of method results. A method is more reliable if it is less subject to error and uses less analyst judgement. Method sensitivity and reliability are difficult to evaluate since the variables which determine them are dependent on one another.

The sensitivity evaluation is based on the following assumptions:

1) Number of vegetation classes defined: The more classes a method defines, the more sensitive that method is. When a method defines many classes, less obvious changes in the vegetation can be detected earlier than would be possible using a method which defines very few classes. Vegetation classes/method are defined as all classes identified using all data sets available to the method. Thus, airphoto grid analysis defined 19 classes (Table 28) although 16 vegetation classes are the maximum number defined on one photo at a time.

2) Data type affects method sensitivity. Species stem counts data are considered more sensitive than either presence-absence data or airphoto data as they are able to record change in species densities. Presence-absence data are considered the next most sensitive data type since they function at the species level, recording change in species presence. Airphoto data are considered the least sensitive of the data types since they record change at the community level.

To assemble a sensitivity index, number of classes and data type were recorded as follows: Methods defining 12 to 19 vegetation classes were assigned a high sensitivity rating; methods defining 8 to 11 classes were assigned a medium sensitivity rating; method defining 3 to 5 classes were assigned a low sensitivity rating. Methods using species stem counts data were assigned a high sensitivity rating; methods using presence-absence data were assigned a medium sensitivity rating; and methods using airphoto data were assigned a low sensitivity rating.

Table 40 lists the nine methods, together with each method's rating in terms of the number of classes defined and the data type. These two ratings are combined into a sensitivity rating. Subjective classification which rated high for the number of classes defined and the data type, is the most sensitive method. Association analysis, airphoto grid analysis and airphoto interpreted vegetation mapping all rated next with either high-low or medium-high ratings. Structure analysis, airphoto monitoring, and computer-assisted mapping were all assigned a medium-low sensitivity rating. Disturbance mapping is the least sensitive method with a low-low rating.

A reliability rating was assembled based on the following assumptions:

1) Airphoto data collection repeatability is greater than either species presence-absence data repeatability or species stem counts data. This is because airphoto specifications (altitude, allowable percent cloud cover, etc.) insure consistent high quality data. Species presence-absence data are less exacting to collect than species stem counts data and are therefore more repeatable.

2) Subjectivity of data-analyst interaction. The more opportunity for subjective data-analyst interaction, the less reliable a method is believed to be. All airphoto interpreted methods are subjective. Computer-assisted mapping requires many subjective analyst decisions which affect final results. Subjective classification and structure analysis both quantitatively define each vegetation class, removing some subjectivity. The diversity index is a purely numerical method while association analysis is objective and entirely repeatable once the analyst selects a species analysis method and options.

3) Quantitative/qualitative results. Quantitative results are assumed to be more repeatable than qualitative results. Quantitative computerized results are assumed to be more repeatable than quantitative analyst results. Quantitative-analyst results are assumed to be more repeatable than qualitative-analyst results.

In this study, airphoto data were found to have a high repeatability; presence-absence data, a medium repeatability; and species stem counts data, a low repeatability. Methods with minimal subjective data-analyst interaction were given a high repeatability rating; those with moderate subjective data-analyst interaction were given a medium repeatability rating and those methods with extensive subjective data-analyst interaction were given a low repeatability rating.

Quantitative-computer methods were assigned a high repeatability rating; quantitative-analyst methods were assigned a medium repeatability rating. Qualitative-analyst methods were assigned a low repeatability rating.

Table 41 lists each method and its data collection repeatability rating, subjectivity of data-analyst interaction rating, and quantitative or qualitative results rating. Association analysis with a medium-high-high shows the highest reliability rating followed by the diversity index and computer-assisted mapping. Airphoto grid analysis and airphoto interpreted vegetation mapping were rated next with a high-low-medium reliability rating. Subjective classification, structure analysis, airphoto monitoring and disturbance mapping were rated the least repeatable methods with low-medium-medium or high-low-low ratings.

Looking at the reliability and sensitivity of each method, association analysis had the highest repeatability rating (medium-high-high) and a medium-medium sensitivity rating. Subjective classification had a high-high sensitivity rating and low-medium-medium repeatability rating. Airphoto grid analysis and airphoto interpreted vegetation mapping had a high-low sensitivity rating and a high-low-medium repeatability rating. Computer-assisted mapping had a medium-low sensitivity rating and a high-low-high repeatability rating. Structure analysis and airphoto monitoring had a medium-low sensitivity rating. Structure analysis had a low-medium-medium repeatability rating while airphoto monitoring had a high-low-low rating. Disturbance mapping had the lowest repeatability and sensitivity ratings with a high-low-low reliability rating and a low-low sensitivity rating. As the diversity index did not define classes, it could not be assigned a sensitivity rating. However, it was assigned a medium-high-medium reliability rating.

## THE GROUND SAMPLING DATA METHODS

Training as a botanist-ecologist is required to 1) collect the ground sampling data that insures correct identification of vegetation species; 2) define the vegetation classes used in the subjective and structure analysis classifications; and 3) label the clusters created using association analysis. Computer experience is necessary when using association analysis. Data collection materials costs totalled $177 (Table 31) for 62 metal stakes, two circular quadrats, data sheets and transportation to and from the site.

### Diversity Index

The diversity index, based on presence-absence data, provides information about the changes in numbers of species with time. This method only indicates if the total number of different species varies with time; it does not identify which species appear or disappear with time.

Twenty-one hours are required to carry out this method, placing it in a medium time intensive class (Table 36). The total cost of processing one set of data is $453; if four sets of data are processed, the total cost is $1,104.

The advantages of this method are: 1) it offers a quantitative index of species change; 2) it is easy to use in any size area; and 3) it is a reliable, medium time intensive and low cost method. Its greatest disadvantage is that it offers only species presence information, not the replacement of one species by another. Also, this method automatically interprets increased or decreased diversity as either negative or positive change.

## Subjective Classification

The subjective classifcation, based on stem counts data, provides information about changes in community location and trends in change which the various communities are undergoing, year by year. When sampling station classifications are mapped, they provide a rough visual presentation of change in community location and area.

The subjective classification is one of the three most time intensive methods, requiring 42 h. Total cost to collect and analyze one set of data is $703. Total cost to collect and analyze four sets of data is $2,026, making this the most expensive of the ground sampling data methods (Table 37).

Subjective classification, the most sensitive of the ground data sampling methods, was given the highest possible sensitivity rating but only a low-medium-medium reliability rating.

The disadvantage of this method is its time intensiveness which results from the time necessary to collect stem counts data. Two hundred data points (which take two people 4 to 5 days to collect and one person 18 h to analyze) might well be the upper limit in using this method.

## Association Analysis

Association analysis, based on presence-absence data, provides information about vegetation changes in community type, community location, and area and trends in change which communities are undergoing year by year.

This method, requiring 24 h to collect and analyze one data set, was rated medium in time intensiveness. Total cost/data set is $614 and $1,476 for four data sets (Table 37).

The sensitivity of association analysis was rated medium-medium while its reliability was rated medium-high. It was rated medium in terms of time intensiveness and low in cost which indicates that it is a moderately to highly efficient method.

An advantage of association analysis is the semi-objective and very reliable classification that it offers. Once the data are collected and the analyst has selected the species and the program options to be used, the classification is done in a standard manner by the computer. Use of presence-absence data helps keep data collection time down. While data analysis costs are related directly to data matrix size, this method can handle large data sets in a short period of time.

## Structure Analysis

Structure analysis shows changes in vegetation structure based on the percent of total cover area of individual vegetation classes. This method provides information about change of community structure in terms of location and area. It shows changes in community area and in community location if classified data from all the sampling stations are mapped, point by point, with time.

This method falls into the medium time intensiveness category requiring 21 h to collect and analyze one data set. Total cost for one data set is $441. Total cost for four data sets is $1,192.

Structure analysis is less sensitive than the other classification methods since it defines only five vegetation classes as the basis of recording structure changes. Both species and community change could occur within an area without a change occurring in structure and this method would not record it.

Structure analysis was rated as low-medium in terms of sensitivity and as low-medium-medium in terms of reliability. It was rated medium in terms of time intensiveness but it was rated low in cost, meaning it has medium-high efficiency.

The structure analysis method is only effective as a monitoring tool in those situations where the change under study involves actual changes in vegetation structure (e.g., a situation where shrubs/trees invade a grassland). Neither the amount of time this method takes nor its total cost undercut the costs of the other two classification methods enough to make up for the lesser quality of information it yields. Because this method can only detect major change, it will tell what has happened in an area, but not how change is happening--an important consideration in most monitoring situations.

## AIRPHOTO DATA ONLY METHODS

A botanist-ecologist with airphoto interpretation skills is best suited to do airphoto interpretative monitoring and disturbance mapping (Table 29). Data materials cost, including airplane rental, photographer fees, film and film processing, come to $271/roll each of color and color infrared film. Capital equipment costs for a two camera, 70 mm format system come to approximately $10,790. Therefore the costs of data materials and data collection equipment are far higher using airphoto data than using ground sampling data (Tables 30 and 31).

## Airphoto Monitoring

Airphoto monitoring offers a visual record of change with time in the form of a series of photos. This method does not require ground verification. Results using this method may be presented as a written description.

Capital equipments costs (Tables 30 and 33) for this method are approximately $23,000. Material cost is $274/airphoto analyzed. Airphoto monitoring is a rapid method to carry out, requiring only 4.75 h from start to finish. Total cost for analyzing one airphoto is $352. The cost of analyzing four airphotos is $1,357, making this an inexpensive method (Table 37).

Airphoto monitoring potentially offers a detailed data base with which to demonstrate change with time, however, since it does not define many vegetation classes and uses only airphoto data, it was assigned a medium-low sensitivity rating (Table 40). Airphoto monitoring was assigned a high-low-low reliability rating because vegetation class data are not quantified, and the method allows for many subjective analyst-data interactions. This method takes the least time (Table 36) and is rated as a low cost method. It has the highest possible combined time-cost (efficiency) rating.

Airphoto monitoring offers a quickly accessible visual interpretation of an airphoto from which a written description can be made. This method can be used to define obvious vegetation and land use classes in areas where on-the-ground access is not possible (Hubbard and Grimes 1972). No provision is made with this method for collecting ground verification data. This keeps down costs but lessens the method's information content. This method's greatest disadvantage is that information gathered is neither quantifiable nor mapped; it can only be as good as the analyst's skill in using it.

In summary, the primary advantages of airphoto monitoring are 1) if changes that can be detected visually are taking place, they can be detected using this method; 2) this method can be used to monitor areas that are inaccessible on the ground; 3) this is an expensive method in terms of time and costs (discounting capital equipment); and 4) it can be used to monitor large sites.

## Disturbance Mapping

Disturbance mapping offers a series of readable maps delineating undisturbed and disturbed vegetation and open water. Disturbance mapping, which defines only three classes, was rated the most insensitive method. It has a high-low-low reliability rating.

Capital equipment costs (camera equipment and color additive viewer costs) for disturbance mapping data collection and analysis is approximately $27,000 (Tables 30 and 33). The cost for materials is approximately $275.

A disturbance map takes between 6.5 and 8.75 h to generate (from start to finish), depending on photo scale. Total cost for one map is $398 (discounting capital equipment); for a series of four maps it is $1,497. Disturbance mapping has the highest possible efficiency rating.

The advantage of disturbance mapping is its provision of a highly readable set of maps which are very sensitive in delineating generalized disturbance. The disadvantage of this method lies in the small number of vegetation classes it defnes. As a result of this, disturbance mapping offers no information on how specific communities are changing.

## AIRPHOTO GRID ANALYSIS, AIRPHOTO INTERPRETED VEGETATION MAPPING AND COMPUTER ASSISTED MAPPING

A botanist-ecologist trained in airphoto interpretation is best suited to use airphoto grid analysis and airphoto interpreted vegetation mapping. Computer-assisted mapping requires an analyst with the skills listed above plus training in computer-assisted mapping and experience in manipulating data between computer mass storage and data tapes.

Data materials costs for these methods are the same as for the two methods involving airphoto data exclusively. Film and film processing costs come to $271 for a roll each of color and color infrared film. Two 70 mm format cameras, including bodies, lenses, filters and film cans, cost $10,800. Data acquisition time for each of these three methods is approximately 4 h. This includes loading film, taking cameras to and from the airport and allowing 1 h flying time.

### Airphoto Grid Analysis

Capital equipment cost (for camera equipment and a stereoscope and light table) for airphoto grid analysis comes to approximately $23,000. Total materials cost to analyze one airphoto is $279. Data collection and analysis time required per airphoto is 50 h. Total analysis cost/airphoto is $1,070; for four airphotos it is $3,420.

Airphoto grid analysis was assigned a high-low sensitivity rating along with vegetation mapping. Its reliability is rated as high-low-medium. Airphoto grid analysis is a time and cost intensive method. Due to its high time and dollar costs, its overall efficiency rating is low-low.

Airphoto grid analysis is a sensitive method in terms of the number of classes which can be identified using it. It is a quantifiable method yielding community percent cover information. Performed on records obtained with time, this method documents changes in each community. This method can be reliable if the airphotos are consistent in scale and quality and if interpretation is consistent. An airphoto interpretation key will help provide consistency among analysts. Frequent reference to ground sampling data increases the sensitivity and reliability of the method.

Using airphoto grid analysis, percent cover change in area can be detected for species which form large clones (such as cattail). Percent cover changes in communities also can be detected. The method is well suited for use in any monitoring situation where the work is done by one analyst since this ensures consistency in interpretation.

This method is well suited to use with many airphotos and/or large areas. It is the third most expensive in terms of the total cost for four runs and it is the second most intensive in terms of time. It is one of three quantifiable methods and ranks second in the number of classes it defines.

## Airphoto Interpreted Vegetation Mapping

Capital equipment costs for vegetation mapping (which requires the use of camera equipment and a color additive viewer) are approximately $27,000. Materials costs are $281/airphoto mapped. Total production time of one map will take 54 to 58 h depending on the scale of the airphoto (larger scales providing more detail take longer). (Forty-two of the hours required for vegetation mapping stem from subjectively classifying the ground verification data. This time can be reduced by using association analysis for ground verification data.) Total cost to produce one map is $1,180; total cost to produce four maps is $3,760.

Vegetation mapping was assigned a high-low sensitivity rating while its reliability was assessed at high-low-medium. This method's highest cost and time requirements give it the lowest possible efficiency rating.

Vegetation mapping is the most sensitive method in terms of numbers of vegetation classes it can show with time. Its sensitivity and reliability are made possible by frequent reference to ground sampling data.

This method shows changes in area and location of species such as *Typha latifolia* and *Scirpus fluviatilis* which form large clones. Changes in community location and area are recordable with time. Since the maps were not drawn on a standard base map, they could not be overlaid and percentage changes in community area could not be figured. If these maps had been drawn on an orthophoto base map blown up to an appropriate scale, this would have been possible. (A grid was laid over each map and numbers of cells/vegetation class counted to determine relative percent of each class.) Labelling each class with a letter made it difficult to keep track of the changes revealed in a series of maps. A multiple pattern and gray tone photographic process should be used to make detailed maps which are legible.

The great advantage offered by airphoto interpreted vegetation mapping is the amount of visual detail it provides; detail showing change in area and location of communities. It is the most time intensive and costly method. Its cost increases with larger photo scale and area. Its strongest points are the detail it offers and its potential overlay capability.

## Computer-Assisted Mapping

Computer-assisted mapping offers consistent classification of vegetation classes and quantification of the area enclosed by each class. In addition the method offers the most readable visual product in the form of computer printed maps or color photo maps.

In-house capital equipment costs for computer-assisted mapping are $110,000 (for camera equipment and scanning microdensitometer, Tables 30 and 33). This method rates medium in terms of intensiveness; 22 h are required to generate one map. And in terms of cost, this method rates third out of the nine methods. One map costs $948 to generate while a series of four costs $2,935.

Considerable expertise is needed to use this method. An analyst should expect to have 60 to 80 h experience with its programs before turning out a classification in 20 to 30 h. As the computer-assisted mapping system now exists, experience in key punching and magnetic tape and mass storage file manipulation is necessary.

Computer-assisted mapping was assigned a sensitivity rating of medium-low and a reliability rating of high-high-low. Its time-cost rating is medium-high making it a moderately efficient method.

The sensitivity of this method is hampered by the confounding of vegetation spectral response patterns. Such confounding prevents the identification of a large number of vegetation classes. The inability to define more classes in this particular study was due to the analyst's inability to select training sets from areas of a known vegetation type. Since no site specific targets were available, correct labelling of classes could not be assured. These two problems could be overcome by putting out permanent targets which would be visible on each airphoto.

A prime disadvantage of this method is its high cost if the method is to be used in-house. Capital equipment costs exceed $100,000. Computer-assisted maps are costly to generate and required medium time intensiveness. Since computer-assisted mapping involves so many steps where there is room for variation in results, the reliability (repeatability) of this method may not be great. Lastly the method requires considerable training and experience to use it.

The advantages of this method are: 1) it classifies consistently across an entire scene so that while a particular class is not known, it is known that all or most of it is being classified; 2) this method quantifies the area mapped for each class in units of the analyst's choice; and 3) this method generates color photo maps of the scene classified which are the most immediately readable products generated by any of the mapping methods. The method's value is enhanced by the fact that similar computer-assisted mapping methods are being developed and promoted for use in the U.S. Department of Interior.

## SECTION 6

## DISCUSSION

The questions raised in this study were:

1) Using these methods, can species changes be detected with time?

2) Which methods detect species changes most efficiently?

3) Using these methods, can community area and location changes be detected with time?

4) Which methods detect community change most efficiently?

5) Can trends in vegetation changes be documented by these methods?

6) Which methods do so most efficiently?

For purposes of this study, an efficient method is defined as a low cost method which takes little time to use. Table 39 rates the methods by time and cost to use them, providing an efficiency rating.

Based on the results of this study, the diversity index recorded species change most efficiently, however, it records change in numbers of species only. Subjective classification and association analysis recorded species change indirectly, through changes in the numbers of stations classified as a particular community. (Community classifications changed as species showed declines or increases in numbers or disappeared altogether.) Subjective classification was based on species counts data and as such gave the more sensitive analysis but association analysis is a less expensive method to use.

Community changes in area and/or location were demonstrated by all methods except the diversity index. All three classification methods showed change based on community point location (for 62 sampling stations). Airphoto methods showed changes in community area and location more clearly than the ground sampling method. Grid analysis, assigned a high-low sensitivity rating, recorded percent area change of communities. Although this method records the grid cell location of each community, this information was not mapped in any way. Airphoto monitoring displays changes on airphotos of community location and area but does not visually record manually or delineate them in any way. Both airphoto interpreted vegetation mapping and computer-assisted mapping visually define communities and quantify percent changes in area. Changes in community location can be inferred by looking at a series of maps generated with time. An overlay capability could be built into these methods that would allow location changes to be quantified. Photo interpreted vegetation mapping and computer-assisted mapping are time consuming methods. If it is sufficient to show only disturbed and undisturbed vegetation, disturbance mapping is the most efficient method to show change in community location and area.

The methods which provided the most information on trends in community change were subjective classification and association analysis. Subjective classification is ranked medium-low for efficiency. Association analysis, a more efficient classification method, is recommended as the second best community trend demonstrating method. These two classification methods are mentioned first because in classifying community data at a number of points with time, they record the steps of deterioration which the various communities move through going from an undegraded to a degraded state. Structure analysis demonstrated trends in the physical structure of the vegetation from grasslike vegetation to tall-coarse vegetation and open water areas.

Most of the methods based on airphoto data show the community trends taking place at the study site. Airphoto monitoring provides photos which have the information but an analyst must interpret them to show change. Airphoto grid analysis demonstrated the trend from grasses and sedges to emergents, degraded vegetation and open water using percent community cover information. Disturbance mapping with the highest possible efficiency rating shows the increase in disturbed area and open water over 3 yr time.

Airphoto interpreted vegetation mapping and computer-assisted mapping demonstrate community trends for classes ranging from sedges and grasses to disturbed vegetation and open water using community percent cover estimates. Of the two methods, airphoto interpreted vegetation mapping is less efficient.

## USING METHODS TOGETHER

Ground data classification methods can be used to advantage with airphoto data mapping methods because the classification will demonstrate the stages in which change is occurring while the mapping methods will show where change is occurring.

Subjective classification, a very time intensive method, can be used with small data sets to demonstrate vegetation trends. With larger data sets, it is better to use association analysis. Airphoto grid analysis, airphoto interpreted vegetation mapping or computer-assisted mapping provide percent cover change information. Airphoto interpreted vegetation mapping, like subjective classification, is best suited to mapping smaller areas (200 ha or less) whereas airphoto grid analysis and particularly computer-assisted mapping can be used along with association analysis to monitor large areas.

Two compatible methods are airphoto grid analysis, which documents percent cover change, and disturbance mapping, which visually shows the areal extent of the change. The two methods are well suited for use in large areas.

Airphoto monitoring and disturbance mapping can be used in areas which are inaccessible on the ground because no ground verification data are required.

Disturbance mapping is a quick, inexpensive, reliable method combination to show change in a disturbed area. Association analysis provides a good supplemental analysis substantiating the disturbance mapping by showing with changes in communities year by year.

If computer-assisted mapping is streamlined by using an interactive graphics terminal for training set selection, classification verification, etc., and if ground verification areas are targeted so known training sets can be identified on imagery, this will be the ideal method to use on large data sets in combination with association analysis. Association analysis can be used to classify ground data and this information can be tied into surveyed target points to identify the mapped classes. Based on this study, the visual displays and quantitative presentation of vegetation class area offered by computer-assisted mapping make it the most valuable mapping method.

# REFERENCES

An annotated bibliography on remote sensing for vegetation mapping is presented in Appendix H.

Anderson, R. R., and F. J. Wobber. 1973. Wetlands mapping in New Jersey. Photo. Eng. 39(4):353-358.

Andrews, C. 1977. Sensing and predicting thermal pollution of ground water. In: Proceedings of the Fourth Joing Conference on Sensing of Environmental Pollutants. American Chemical Society. Washington, D.C. p. 105-115.

Bedford, B. L. 1977. Changes in wetland vegetation associated with leakage from the cooling lake of a coal-fired power plant. M.S. Thesis. University of Wisconsin-Madison, Madison, Wis. 37 p.

Bisset, J. 1978. Quantification, decision making and environmental impact assessment in the United Kingdom. J. Environ. Management 7:43-58.

Brown, W. Wetland mapping in New Jersey and New York. Photo. Eng. 44(3):303-314.

Buchanan, W. J. 1977. Applications of digitized film analysis and perceptions of possible users. M.S. Thesis. University of Wisconsin-Madison, Madison, Wis. 124 p.

Bunce, R. G. H., and M. W. Shaw. 1973. A standardized procedure for ecological survey. J. Environ. Management 1:239-258.

Civco, D. L., W. L. Kennard, and M. L. Lefor. 1978. A technique for evaluating inland wetland photointerpretation: the cell analytical method (CAM). Photo. Eng. 44(8):1045-1052.

Cowardin, L. M., and V. I. Meyers. 1971. Remote sensing for identification and classification of wetland vegetation. J. Wild. Management. 38(2):308-314.

Dames and Moore, Inc. 1972. Environmental consultants. Chicago, Il.

Dirschl, H. J., and D. L. Dabbs. 1972. The role of remote sensing in wildland ecology and environmental impact studies. In: Proceedings of the First Canadian Symposium. Ottawa, Ontario. p. 337-344.

Eberhardt, L. L. 1976. Quantitative ecology and impact assessment. J. Environ. Management 4:27-70.

Enslin, W. R., and M. C. Sullivan. 1974. The use of color infrared photography for wetland assessment. In: Remote Sensing of Earth Resources Conference. The University of Tennessee Space Institute. Tullahoma, Tennessee. Vol. III. p. 697-720.

Evans, Kent. 1979. Personal communication. Enviro Control. Chicago.

Fischer, T. W., and G. S. Davies. 1973. An approach to assessing environmental impacts. J. Environ. Management 1:207-227.

Fornes, A. O., and J. R. Reimold. 1973. The estuarine environment: location of mean high water--its engineering, economic and ecological potential. Part II. In: Proceedings, Am. Soc. of Photogrammetry Fall Convention. Lake Buena Vista, Florida. p. 938-978.

Frazier, B. E., and G. B. Lee. 1975. Effectiveness of a computer land use planning system utilizing data. In: Proceedings of the Amer. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 754-777.

Gallagher, J. L., D. E. Thompson, and R. J. Reimold. 1972. Remote sensing and salt marsh productivity. In: Proceedings, Am. Soc. Photogrammetry Symposium on Coastal Mapping. Washington, D.C. p. 18-31.

Gammon, P. T., and V. Carter. 1979. Vegetation mapping with seasonal color infrared photographs. Photo. Eng. 45(1):87-97.

Goodenough, D., and S. Shlien. 1974. Results of cover-type classification by maximum likelihood and parallelepiped methods. In: Proceedings of the Second Canadian Symposium on Remote Sensing. Guelph, Ontario. p. 135-144.

Hough, A. F. 1965. A twenty year record of understory vegetational change in a virgin Pennsylvania forest. Ecology 46(5):370-373.

Hubbard, J. C. E., and B. H. Grimes. 1972. Coastal vegetation surveys. In: Environmental Remote Sensing: Applications and Achievements, Eric C. Barrett and Leonard F. Curtis, eds. Crane and Russak, New York. p. 129-141.

Jaeger, J. M. 1979. Predicting effects of an electrical generating station on wetland passerine birds. Environmental Research Laboratory-Duluth. U. S. Environmental Protection Agency. 57 p.

Johnson, B. G. 1974. Developing data for environmental impact studies. J. of Tech. Ass. of the Pulp and Paper Industry. 57(9):81-84.

Kalman, L. S., and F. L. Scarpace. 1979. Determination of lens falloff through digitized analysis of photographic imagery. In: Proceedings of the Am. Soc. of Photogrammetry 45th Annual Meeting, Washington, D.C. p. 116-135.

Lillesand, T. M., and R. W. Kiefer. 1979. Remote sensing and image interpretation. John Wiley & Sons. New York. 612 p.

Leopold, L. B., F. E. Clarke, B. B. Hanshaw, and J. R. Balsley. 1971. A procedure for evaluating environmental impact. Geological Survey Circular 645. Washington, D.C. 13 p.

McHarg, I. 1969. Design with nature. National History Press. Garden City, New York. 197 p.

Meyer, Merle. 1977. Personal communication. University of Minnesota, Minneapolis, Minnesota.

Muller-Dombois, D., and H. Ellenberg. 1975 Aims and methods of vegetation ecology. John Wiley & Sons. New York. 547 p.

Niemann, B. J., Jr. 1979. Personal communication. University of Wisconsin-Madison, Madison, Wisconsin.

Niemann, B. J., Jr., X. A. Bonilla, S. R. Bruno, and R. A. Rose. 1975. Rural landscape assessment: a comparative evaluation of high platform remote sensors. Dep. of Interior, BOR, and College of Agriculture and Life Sciences, University of Wisconsin-Madison, Madison, Wisconsin. 243 p.

Rainwater, C. 1971. Light and color. Western Publishing Company, Ind. New York. 160 p.

Scarpace, F. L. 1979. Personal communication. University of Wisconsin-Madison, Madison, Wisconsin.

Scarpace, F. L. 1978. Densitometry on multi-emulsion imagery. Photo. Eng. 44(10):1279-1292.

Scarpace, F. L., L. T. Fisher, and B. Quirk. 1978. Programs for digital processing. Remote Sensing Group, Institute for Environmental Studies. University of Wisconsin-Madison, Madison, Wisconsin.

Scher, J. S., and P. T. Tueller. 1973. Color aerial photos for marshlands. Photo. Eng. 39:480-499.

Shima, J. L. 1973. Wetland vegetation mapping using aerial, color infrared photography. M.S. Thesis. The American University. Washington, D.C. 34 p.

Shima, J. L., R. R. Anderson, and V. P. Carter. 1976. The use of aerial color photography in mapping the vegetation of a freshwater marsh. Chesapeake Science 17(2):74-85.

Siegal, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, Inc. New York. 312 p.

Smith, D. W., R. Suffling, D. Stevens, and T. S. Dai. 1975. Plant community age as a measurement of sensitivity of ecosystems to disturbances. J. Environ. Management 6:27-42.

Swain, P. H., and S. M. Davis, eds. 1978. Remote sensing: the quantitative approach. McGraw-Hill. New York. 376 p.

Thompson, D. E. 1972. Airborne remote sensing of Georgia tidal marshes. In: Operational remote sensing: an interactive seminar to evaluate current capabilities. Am. Soc. of Photogrammetry. Houston, Texas. p. 126-139.

Wacker, A. G., and D. A. Landgrebe. 1972. Minimum distance classification in remote sensing. In: Proceedings of the First Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 577-599.

Warner, M. L., and D. W. Bromley. 1974. Environmental impact analysis: a review of three methodologies. University of Wisconsin-Madison. Institute for Environmental Studies. Departments of Forestry and Agriculture Economics and Water Resources Center, Technical Report. 65 p.

Whitman, R. I., and K. L. Marcellus. 1973. Textural signatures for wetland vegetation. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Lake Buena Vista, Florida. p. 979-992.

Williams, W. T., and J. M. Lambert. 1959. Multivariate methods in plant ecology. I. Association analysis in plant communities. J. Ecol. 47:83-101.

Williams, W. T., and J. M. Lambert. 1960. Multivariate methods in plant ecology. II. The use of an electronic computer for association analysis. J. Ecol. 48:689-710.

Wishert, D. 1970. Clustan IA User Manual. Computer Laboratory, University of St. Andrews, St. Andrews, Scotland. p. 118.

# APPENDIX A

## SPECIES CODE LIST

TABLE A-1. SPECIES CODE LIST

| Species Code | |
|---|---|
| No. | Species |
| | VISUAL DOMINANTS |
| 1. | *Acorus calamus* |
| 2. | *Calamagrostis canadensis* |
| 3. | *Carex aquatilis* |
| 4. | *Carex emoryi* |
| 5. | *Carex haydenii* |
| 6. | *Carex lacustris* |
| 7. | *Carex lasiocarpa* |
| 8. | *Carex rostrata* |
| 9. | *Carex stricta* |
| 10. | *Dryopteris thelypteris* |
| 11. | *Eupatorium manculatum* |
| 12. | *Eupatorium perfoliatum* |
| 13. | *Helianthus grossesserratus* |
| 14. | *Iris shrevii* |
| 15. | *Learzia oryzoides* |
| 16. | *Lemna minor* |
| 17. | *Onoclea sensibilis* |
| 18. | *Polygonum coccineum* |
| 19. | *Polygonum natans* |
| 20. | *Rumex orbiculatus* |
| 21. | *Rumex verticillatus* |
| 22. | *Sagittaria latifolia* |
| 23. | *Scirpus cyperinus* |
| 24. | *Scirpus fluviatilis* |
| 25. | *Scirpus validus* |
| 26. | *Solidago gigantea* |
| 27. | *Spartina pectanata* |
| 28. | *Sparganium eurycarpum* |
| 29. | *Spirea alba* |
| 30. | *Typha latifolia* |
| | NUMERICAL DOMINANTS |
| 31. | *Asclepia incarnata* |
| 32. | *Aster sp.* |
| 33. | *Aster lucidulus* |
| 34. | **Aster puniceps** |
| 35. | *Aster simplex* |
| 36. | *Bidens cernua* |
| 37. | *Bidens coronata* |
| 38. | *Biehmeria cylindrica* |
| 39. | *Campanual aparinoides* |
| 40. | *Cardamine bulbosa* |
| 41. | *Carex lanuginosa* |
| 42. | *Carex sartwellii* |
| 43. | *Carex stipata* |
| 44. | *Carex vesicaria* |
| 45. | *Chenopodium album* |
| 46. | *Cicuta bulbifera* |
| 47. | *Eleocharis acicularis* |
| 48. | *Eleocharis compressa* |
| 49. | *Eleocharis palustris* |
| 50. | *Equisetum arvense* |
| 51. | *Equistum fluviatile* |
| 52. | *Galium tinctorium* |
| 53. | *Juncus brachycephalis* |
| 54. | *Lycopus sp.* |
| 55. | *Lycopus americanus* |
| 56. | *Lycopus uniflorus* |
| 57. | *Lycopus virginicus* |
| 58. | *Lysimachia sp.* |
| 59. | *Lysimachia terristris* |
| 60. | *Lysimachis thysiflora* |
| 61. | *Mentha arvensis* |
| 62. | *Mentha spicata* |
| 63. | *Phlox pilosa* |
| 64. | *Piloa pumila* |
| 65. | *Polygonum sp.* |
| 66. | *Polygonum hydropiper-hydropiperoides* |
| 67. | *Polygonum sagittatum* |
| 68. | *Potentilla palustris* |
| 69. | *Sium sauve* |
| 70. | *Acer saccharinum* |
| 71. | *Acer saccharum* |
| 72. | *Agropyron repens* |
| 73. | *Agrostis alba* |
| 74. | *Agrostis scabra* |
| 75. | *Alisma plantago-aquatica* |
| 76. | *Alnus sp.* |
| 77. | *Ambrosia artemisiifolia* |
| 78. | *Anemone canadense* |
| 79. | *Andropogron gerardi* |
| 80. | *Apocynum sibiricum* |
| 81. | *Asclepias syriaca* |
| 82. | *Aster pilosus* |
| 83. | **Bidens frondosa** |
| 84. | *Botrychium obliquum* |
| 85. | *Carex atherodes* |
| 86. | *Carex bebbii* |
| 87. | *Carex comosa* |
| 88. | *Carex granularis* |
| 89. | *Carex prairea* |
| 90. | *Carex tribuloides* |
| 91. | *Cenchis longispinus* |

**Appendix A (continued)**

| Species Code | |
|---|---|
| No. | Species |
| 92. | *Cerastium vulgatum* |
| 93. | *Cicuta sp.* |
| 94. | *Cirsium vulgare* |
| 95. | *Convolvulus sepium* |
| 96 | *Convolvulus spithameus* |
| 97. | *Conysa canadensis* |
| 98. | *Cornus obliqua* |
| 99. | *Cornus racemose* |
| 100. | *Cornus stolonifera* |
| 101. | *Cuscuta gronovii* |
| 102. | *Cyperus sp.* |
| 103. | *Echinochlea pungens* |
| 104. | *Elcocharis obrusa* |
| 105. | *Epilobium coloratum* |
| 106. | *Epilobium leptophyllum* |
| 107. | *Equisetum hyemale* |
| 108. | *Erechtites hieracifolia* |
| 109. | *Erigeron sp.* |
| 110. | *Erigeron philadelphicus* |
| 111. | *Festuca elatior* |
| 112. | *Festuca ovina* |
| 113. | *Geranium maculatum* |
| 114. | *Gerardia paupercula* |
| 115. | *Geum aleppicum var. strictum* |
| 116. | *Helenium autumale* |
| 117. | *Hypericum kalmianum* |
| 118. | *Hypericum majus* |
| 119. | *Impatiens biflora* |
| 120. | *Ipomoea biflora* |
| 121. | *Iris virginicum* |
| 122. | *Juncus nodosus* |
| 123. | *Lathyrus palustris* |
| 124. | *Laportea canadensis* |
| 125. | *Lepidium campestre* |
| 126. | *Lepidium virginicum* |
| 127. | *Lespadeza capitatum* |
| 128. | *Liatrus pycnostachya* |
| 129. | *Lobelia kalmii* |
| 130. | *Lobelia siphilitica* |
| 131. | *Lidvegia palustris* |
| 132. | *Lysimachia ciliata* |
| 133. | *Marchantia sp.* |
| 134. | *Medicago lupulina* |
| 135. | *Medicago sativa* |
| 136. | *Melilotus officinalis* |
| 137. | *Mentha piperata* |
| 138. | *Osmunda regalis var. spectabilis* |
| 139. | *Panicum capillare* |
| 140. | *Panicum flexile* |
| 141. | *Panicum praecocius* |
| 142. | *Penthorum sedoides* |
| 143. | *Phalaris arundinacea* |
| 144. | *Phleum pratense* |
| 145. | *Poa canadensis* |
| 146. | *Poa compressa* |
| 147. | *Poa pratensis* |
| 148. | *Polygonum convolvulus* |
| 149. | *Polygonum lapathifolium* |
| 150. | *Polygonum norvegica* |
| 151. | *Polygonum pensylvanicum* |
| 152. | *Pontederia cordata* |
| 153. | *Populus sp.* |
| 154. | *Populus deltoides* |
| 155. | *Populus tremuloides* |
| 156. | *Pycnantheumu virginianum* |
| 157. | *Ranunculus flabellaris* |
| 158. | *Ranunculus longirostris* |
| 159. | *Riccia flutans* |
| 160. | *Ricciocarpus* |
| 161. | *Rorippa islandica* |
| 162. | *Rosa palustris* |
| 163. | *Rubus sp.* |
| 164. | *Rubus hispidus* |
| 165. | *Salix sp.* |
| 166. | *Salix bebbiana* |
| 167. | *Salix candida* |
| 168. | *Salix discolor* |
| 169. | *Salix interior* |
| 170. | *Salix nigra* |
| 171. | *Salix petiolaris* |
| 172. | *Saponaria officinalis* |
| 173. | *Scirpus americanus* |
| 174. | *Scirpus atrovirons* |
| 175. | *Scutellaria galericulata* |
| 176. | *Scutellaria lateriflora* |
| 177. | *Setaria viridis* |
| 178. | *Smilacina stellata* |
| 179. | *Solanum dulcamara* |
| 180. | *Solanum nigrum* |
| 181. | *Solidago sp.* |
| 182. | *Solidago altissima* |
| 183. | *Sporobolus cryptandrus* |
| 184. | *Stachys hispida* |
| 185. | *Stachys palustris* |
| 186. | *Stellaria longifolia* |
| 187. | *Taraxacum officinale* |
| 188. | *Thlaspi arvense* |
| 189. | *Triadenum virginicum* |
| 190. | *Trifolium pratense* |
| 191. | *Trifolium repens* |
| 192. | *Typha angustifolium* |
| 193. | *Vaccinum angustifoloium* |
| 194. | *Verbena hastata* |
| 195. | *Verbena stricta* |
| 196. | *Veronica fasiculata* |
| 197. | *Veronica scutellata* |
| 198. | *Veronicastrum virginicum* |
| 199. | *Vicia americana* |
| 200. | *Vicia villosa* |
| 201. | *Viola sp.* |
| 202. | *Viola cucullata* |
| 203. | *Viola papilionacea* |
| 204. | *Viola sororia* |
| 205. | *Vitus volpina* |
| 206. | *Urtica dioica* |
| 207. | *Utricularia vulgaris* |
| 208. | Unknown |
| 209. | *Lilum superbum* |
| 210. | *Oxalis sp.* |
| 211. | *Allium canadense* |
| 212. | *Cardamine pennsylvanica* |
| 213. | *Ceratophyllum sp.* |
| 214. | *Ribes amercanum* |
| 215. | *Carex sp.* |
| 216. | *Cephalanthus occidentalis* |
| 217. | *Chelone glabra* |
| 218. | *Ringens mimulus* |
| 219. | *Epilobium angustifolium* |
| 220. | Open water |

## APPENDIX B

TABLE B-1. STATION AND TRANSECT NUMBERS[a]

| Station No. | Transect No. | Station No. | Transect No. | Station No. | Transect No. |
|---|---|---|---|---|---|
| 1 | 18 | 22 | 30 | 43 | 35 |
| 2 | 20 | 23 | 31 | 44 | 35 |
| 3 | 21 | 24 | 31 | 45 | 36 |
| 4 | 22 | 25 | 31 | 46 | 36 |
| 5 | 23 | 26 | 31 | 47 | 36 |
| 6 | 24 | 27 | 32 | 48 | 36 |
| 7 | 26 | 28 | 32 | 49 | 37 |
| 8 | 26 | 29 | 32 | 50 | 37 |
| 9 | 27 | 30 | 32 | 51 | 37 |
| 10 | 27 | 31 | 33 | 52 | 37 |
| 11 | 27 | 32 | 33 | 53 | 38 |
| 12 | 28 | 33 | 33 | 54 | 38 |
| 13 | 28 | 34 | 33 | 55 | 38 |
| 14 | 28 | 35 | 33 | 56 | 38 |
| 15 | 29 | 36 | 34 | 57 | 39 |
| 16 | 29 | 37 | 34 | 58 | 39 |
| 17 | 29 | 38 | 34 | 59 | 39 |
| 18 | 29 | 39 | 34 | 60 | 40 |
| 19 | 30 | 40 | 35 | 61 | 40 |
| 20 | 30 | 41 | 35 | 62 | 40 |
| 21 | 30 | 42 | 35 |  |  |

# APPENDIX C

## TABLE C-1. DIVERSITY INDEX

Numbers of Species Found at Each Sampling Station

| Station No. | 1974 | 1975 | 1976 | 1977 | Station No. | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 7 | 6 | 9 | 33 | 4 | 5 | 4 | 3 |
| 2 | 9 | 5 | 4 | 8 | 34 | 5 | 4 | 3 | 3 |
| 3 | 8 | 4 | 2 | 2 | 35 | 6 | 5 | 4 | 4 |
| 4 | 6 | 5 | 11 | 7 | 36 | 5 | 7 | 4 | 3 |
| 5 | 6 | 5 | 2 | 2 | 37 | 7 | 8 | 6 | 5 |
| 6 | 5 | 6 | 7 | 3 | 38 | 5 | 4 | 6 | 3 |
| 7 | 5 | 7 | 6 | 6 | 39 | 6 | 4 | 5 | 4 |
| 8 | 7 | 7 | 4 | 7 | 40 | 6 | 7 | 5 | 6 |
| 9 | 7 | 7 | 6 | 5 | 41 | 9 | 9 | 6 | 8 |
| 10 | 7 | 6 | 3 | 5 | 42 | 5 | 3 | 4 | 2 |
| 11 | 6 | 6 | 3 | 4 | 43 | 5 | 3 | 2 | 2 |
| 12 | 10 | 5 | 6 | 5 | 44 | 5 | 3 | 3 | 2 |
| 13 | 6 | 5 | 3 | 3 | 45 | 6 | 5 | 6 | 8 |
| 14 | 7 | 6 | 6 | 5 | 46 | 7 | 6 | 3 | 5 |
| 15 | 6 | 8 | 6 | 3 | 47 | 5 | 7 | 8 | 5 |
| 16 | 6 | 6 | 5 | 5 | 48 | 6 | 5 | 4 | 4 |
| 17 | 8 | 5 | 5 | 2 | 49 | 5 | 9 | 5 | 5 |
| 18 | 6 | 9 | 5 | 4 | 50 | 9 | 8 | 5 | 9 |
| 19 | 5 | 6 | 3 | 3 | 51 | 6 | 6 | 8 | 6 |
| 20 | 3 | 5 | 5 | 4 | 52 | 8 | 6 | 5 | 6 |
| 21 | 5 | 5 | 4 | 2 | 53 | 5 | 7 | 2 | 3 |
| 22 | 5 | 7 | 3 | 3 | 54 | 6 | 5 | 5 | 10 |
| 23 | 9 | 3 | 4 | 3 | 55 | 5 | 6 | 8 | 7 |
| 24 | 6 | 4 | 2 | 1 | 56 | 5 | 6 | 4 | 4 |
| 25 | 3 | 5 | 5 | 3 | 57 | 6 | 6 | 6 | 7 |
| 26 | 9 | 7 | 5 | 4 | 58 | 6 | 5 | 6 | 7 |
| 27 | 5 | 6 | 6 | 3 | 59 | 5 | 5 | 6 | 8 |
| 28 | 4 | 5 | 3 | 3 | 60 | 6 | 4 | 6 | 7 |
| 29 | 5 | 5 | 4 | 3 | 61 | 7 | 3 | 2 | 0 |
| 30 | 6 | 6 | 5 | 3 | 62 | 6 | 6 | 6 | 8 |
| 31 | 7 | 11 | 6 | 0 |  | 9 | 7 | 6 | 6 |
| 32 | 5 | 6 | 4 | 2 |  |  |  |  |  |

(continued)

Appendix C (continued)

| 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|
| 379/62 = 6.11 | 357/62 = 5.76 | 296/62 = 4.78 | 266/62 = 4.29 |

| 1974 to 1975 | 1975 to 1976 | 1976 to 1977 |
|---|---|---|
| 6.11<br>-5.76<br>0.35 | 5.76<br>-4.78<br>0.98 | 4.78<br>-4.29<br>0.49 |

1.82 overall difference

# APPENDIX D

## TABLE D-1. SUBJECTIVE CLASSIFICATION[a]

| Station No. | 1974 | 1975 | 1976 | 1977 | Station No. | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CL | CL | WA | DCS | 32 | CL | CL | DCL | O |
| 2 | Sp | Sp | Sp | Sp | 33 | E | E | E | DE |
| 3 | E | E | E | O | 34 | T | DT | E | O |
| 4 | Sp | Sp | Sp | Sp | 35 | E | E | DE | DE |
| 5 | CL | O | O | O | 36 | CS | CS | DCS | DCS |
| 6 | CL | CL | CL | CL | 37 | T | T | T | DT |
| 7 | CS | CS | CS | CS | 38 | E | E | E | DE |
| 8 | CS | CS | CS | CS | 39 | E | DE | DE | DE |
| 9 | CL | CL | DCL | DCL | 40 | CL | CL | DCL | WA |
| 10 | CS | CS | DCS | DCS | 41 | CL | WA | WA | WA |
| 11 | CS | CS | DCS | DCS | 42 | E | E | DE | O |
| 12 | Sh | Sh | CS | CS | 43 | E | E | E | DE |
| 13 | T | DT | O | O | 44 | E | E | E | E |
| 14 | Sh | Sh | Sh | Sh | 45 | CS | CS | CS | CS |
| 15 | T | T | DT | DT | 46 | CL | CL | DCL | DCL |
| 16 | T | T | T | DT | 47 | CL | CL | CL | CS |
| 17 | CL | DCL | DCL | DCL | 48 | T | E | E | DE |
| 18 | Sh | Sh | Sh | Sh | 49 | CS | CS | CS | CS |
| 19 | Sh | Sh | Sh | Sh | 50 | CS | DCS | DCS | T |
| 20 | T | T | DT | DT | 51 | CS | CS | CS | CS |
| 21 | E | E | E | E | 52 | CL | CS | SH | O |
| 22 | E | E | E | E | 53 | CS | CS | CS | DCS |
| 23 | Sh | Sh | Sh | Sh | 54 | CS | CS | CS | DCS |
| 24 | T | T | O | O | 55 | Sp | SP | SP | SP |
| 25 | T | E | E | E | 56 | T | T | T | T |
| 26 | E | E | E | E | 57 | CS | CS | CS | DCS |
| 27 | Sh | Sh | Sh | Sh | 58 | CS | CS | CS | DCS |
| 28 | T | T | T | E | 59 | CL | CS | CS | DCS |
| 29 | T | T | DT | E | 60 | CL | CL | CS | DCS |
| 30 | CL | T | DT | E | 61 | CS | CS | CS | CS |
| 31 | CL | CL | DCL | O | 62 | CS | CS | CS | CS |

[a] CS = *Carex stricta*; CL = *Carex lacustris*; E = Emergents; T = Transition; Sp = *Spiraea*; Sh = Shrubs; O = Open; DCS = Degraded *Carex stricta*; DCL = Degraded *Carex lacustris*; DE = Degraded emergents; DT = Degraded transition; WA = Weedy annuals.

# APPENDIX E

## TABLE E-1. ASSOCIATION ANALYSIS[a]

| Station No. | 1974 | 1975 | 1976 | 1977 | Station No. | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CL | CC | WA | WA | 32 | CL | T | T | DLC |
| 2 | Sp | CS | Sp | CS | 33 | T | T | E | E |
| 3 | E | E | E | E-O | 34 | T | E | E | E |
| 4 | CS | Sp | Sp | Sp | 35 | E | E | E | E |
| 5 | CL | CL | O | E-O | 36 | CS | CL | DCS | DCS |
| 6 | CL | CL | CL | DCL | 37 | T | CS | DCS | T |
| 7 | CS | CS | CS | DCS | 38 | T | T | DCS | E-O |
| 8 | CS | CS | DCS | DCS | 39 | T | E | E | DE |
| 9 | CL | T | T | DT | 40 | CS | DCL | O | WA |
| 10 | SL | CS | DCS | DCS | 41 | CL | CL | CS | WA |
| 11 | CS | CS | DCS | DCS | 42 | E | E | E | E-O |
| 12 | CL | T | DCS | DCS | 43 | E | E | E | E-O |
| 13 | CL | T | O | DCS | 44 | E | E | T | DCS |
| 14 | SL | T | T | DT | 45 | CS | CS | CS | T |
| 15 | CL | T | T | DCS | 46 | CL | CL | CS | CS |
| 16 | CL | T | T | DT | 47 | CS | CL | CS | E-O |
| 17 | CL | T | T | E-O | 48 | CS | CS | CS | T |
| 18 | Sh | Sh | Sh | Sh | 49 | CL | CS | DCS | T |
| 19 | Sh | T | T | E-O | 50 | CL | CS | DCS | T |
| 20 | T | T | T | DT | 51 | CS | CS | DCS | DCS |
| 21 | T | E | E | E | 52 | CS | Sh | Sh | Sh |
| 22 | E | E | E | D | 53 | CS | CS | CS | DCS |
| 23 | Sh | Sh | Sh | E-O | 54 | CS | CS | CS | CS |
| 24 | CL | T | O | E-O | 55 | Sp | Sp | CS | CS |
| 25 | T | E | E | E | 56 | CL | CS | T | Sh |
| 26 | E | E | E | E-O | 57 | CS | CS | CS | DCS |
| 27 | Sh | Sh | Sh | Sh | 58 | CS | CS | CS | DCS |
| 28 | T | T | E | E-O | 59 | CL | CS | CS | DCS |
| 29 | T | T | T | E-O | 60 | CS | CS | CS | CS |
| 30 | CL | E | E | E | 61 | Sp | CS | CS | WA |
| 31 | CL | CL | DCS | DCS | 62 | CS | CS | CS | CA |

[a] CS = *Carex stricta*; CL = *Carex lacustris*; T = Transition; E = Emergents; O = Open; Sp = *Spiraea*; Sh = Shrubs; WA = Weedy annual; DCS = Degraded *Carex stricta*; DCL = Degraded *Carex lacustris*; DT = Degraded transition; DE = Degraded emergents; E-O = Emergents-open.

## APPENDIX F

### TABLE F-1. AIRPHOTO INTERPRETATION KEYS FOR AIRPHOTO GRID ASSESSMENT

Grid Interpretation Keys

June 4, 1972 CIR Scale 1:120,000

1. Sedges and grasses--bright pink tone; smooth texture.
2. Transition--light blue tone; fine texture.
3. Emergent--deep blue tone; fine texture.
4. *Spiraea*--deep pink tone; very coarse texture.
5. Open water--blue black tone; smooth texture.
7. Shrub carr--deep pink-magenta tone; smooth texture.

July 31, 1974 CIR Scale 1:120,000

1. Sedges and grasses--pinkish red tone; fine texture.
2. Transition--mixed greenish and red tones; fine texture.
3. Emergents--dark greenish tones; fine texture.
4. *Spiraea*--deep pinkish-red tones; medium texture.
5. Shrubs & trees--dark magenta tone; coarse texture.
6. Open water--none visible in study area on this image.

September 25, 1975 CIR 1:38,200

1. *Carex lacustris*--light lime green tone; fine texture.
2. *Carex stricta*--reddish pink; fine texture.
3. Transition--rich medium-toned green; fine texture.
4. Emergents--dark green to black with coarse red areas mixed in; fine texture.
5. *Spiraea*--medium reddish-green tone; coarse texture.
6. Shrubs & trees--all shades of mottled reds and green tones; definite rounded shapes; very coarse texture.
7. *Lemna minor*--eight whitish pink areas; smooth texture.
8. Open water--dark, black green; smooth texture.

July 24, 1976 CIR 1:19,100

1. *Carex lacustris*--red tones with greenish tinge to them; pitted texture.
2. Degraded *Carex lacustris*--red and green mottled tones; coarse textured and patches of *Lemna minor* mixed in.
3. *Carex stricta*--bright red tones; fine texture.
4. Transition--deeper green tones with scattered red; coarse pitted texture.

Table F-1. Continued

Grid Interpretation Keys

5. Emergents--very green tones; clonal shapes of *Scirpus fluviatilis* and *Typha latifolia*; coarse textured.
6. *Spiraea*--deep red-brown tones; coarse texture.
7. Shrubs and trees--deep red tones; definite round shape; very coarse texture.
8. *Lemna minor*--whitish pink tone; smooth texture.
9. Open water--black tone; smooth texture.

September 24, 1976 CIR 1:19,100

1. Degraded *Carex lacustris*--red tussocks surrounded with pinkish white *Lemna minor*, medium texture.
2. *Carex stricta*--bright red; fine texture.
3. Degraded *Carex stricta*--red tussocks surrounded with pinkish white *Lemna minor*; medium texture.
4. Transition--deep green tones mottled with red; pitted texture.
5. Emergents--deep green tones; coarse texture, some areas of distinctive clones.
6. *Typha latifolia*--deep red-brown colored clones; coarse textured.
7. *Spiraea alba*--greenish red tones; medium tones.
8. Shrubs and trees--green and pink tones; very coarse textured.
9. *Lemna minor*--pinkish white tones; smooth texture.
10. Open Water--deep green, blue-black tones; smooth texture.

June 25, 1977 Color 1:38,200

1. Sedges and grasses--deep green tone; smooth, fine texture.
2. Degraded *Carex stricta*--brownish areas; fine texture.
3. Transition-emergent--deep green and brown tones; more interspersion evident than in sedge-grass areas.
4. *Typha latifolia*--deep green clones; fuzzy texture.
5. *Spiraea*--green areas with coarse texture.
6. Shrubs and trees--dark green, lumpy textured area.
7. *Lemna minor*--bright, chartreuse green; smooth texture.
8. Open water--deep green or muddy brown tones.

June 25, 1977 CIR 1:38,200

1. Degraded *Carex lacustris*--deep red and rust tones with light pinkish tones of *Lemna minor* mixed in; fine texture.
2. *Carex stricta*--bright pink tone; fine texture.
3. Degraded *Carex stricta*--open areas (blue-black) with bright red clumps (tussocks) and scattered pinkish-white tones (*Lemna minor*) pitted texture.
4. Transition--pink toned areas dissected with water and scattered *Lemna minor*.
5. Emergents--deep red-brown tones; medium texture.

Table F-1. Continued

Grid Interpretation Keys

6. *Typha latifolia*--bright deep red tones; coarse texture.
7. *Spiraea alba*--brownish red tones; coarse texture.
8. Shrubs and trees--bright pink, reddish-brown tones; very coarse texture; round shape.
9. Weedy annuals--light pink toned areas containing very sparse vegetation.
10. *Lemna minor*--light-bright pink tones; smooth texture.
11. Open water--blue-black tones; smooth texture.

October 3, 1977 CIR 1:11,500

1. *Carex stricta*--visible greenish tussocks.
2. Degraded *Carex stricta*--green toned clumps (Tussocks) surrounded by pinkish toned *Lemna minor*.
3. Sedges and grasses--green and red tones; fine texture.
4. Degraded sedges--sedge areas pock-marked with areas of open water.
5. *Spiraea alba*--red tones; fine to medium texture.
6. *Typha latifolia*--bright blue green; medium texture.
7. Emergents--blue green and green tones; clone shape with coarse texture.
8. *Lemna minor*--bright pink areas; fine texture.
9. Open water--deep blue tones; smooth texture.
10. Shrubs and trees--pink, red and green tones; definite round crown shapes; very coarse texture.

## APPENDIX G

## TABLE G-1. AIRPHOTO INTERPRETATION KEYS FOR VEGETATION MAPPING

Interpretation Keys

June 4, 1972 1:120,000 CIR

1. Sedges and grasses--bright pink tone with a smooth texture.
2. Transition--light blue tone with a fine texture.
3. Emergents--deep blue tones; fine texture.
4. *Spiraea*--deep pink tone with a coarse texture.
5. Shrubs--magenta tone; very coarse texture.
6. Shrub carr--deep pinkish-magenta tones with a very coarse texture.
7. Open water--blue black tone with a smooth texture.
8. Trees--bright, deep magenta tone; very coarse texture.

July 31, 1974 1:120,000 CIR

1. Sedges and grasses--pinkish red color; fine texture.
2. Transition--greenish and red tones mixed; fine texture.
3. Emergents--dark greenish tones; fine texture.
4. *Spiraea*--deep red color and medium texture.
5. Shrubs and trees--dark magenta tones with coarse texture.
6. Open water--black-blue tones with a flat texture.

September 25, 1975 CIR Scale 1:38,200

1. *Carex lacustris*--bright lime green; fine texture.
2. *Carex stricta*--reddish pink; fine texture.
3. Degraded *Carex stricta*--greenish red clumps in pink matrix of *Lemna minor*.
4. Transition--rich medium toned green; fine texture.
5. Degraded transition--greenish areas with interspersion; fine textured.
6. Emergents--dark green to black with coarse red areas mixed in; fine textured along stream.
7. *Scirpus fluviatilis*--bright white green area; coarse texture at back of site in the southern end of the site.
8. *Spiraea alba*--medium reddish-green tone; coarse texture primarily in the southern end of the site.
9. Shrubs--very bright pink red tone with a coarse texture.
10. *Lemna minor*--very bright whitish pink area with a flat texture.
11. Open water--dark black green with a smooth texture.

Table G-1. Continued

---

Interpretation Keys

---

12. Shrub carr--coarse greenish-reddish area at southern end of study site. Individual shrub crowns visible.
13. Trees--very red tones; coarsest vegetation on the photo; all tree crowns visible.

July 26, 1976 CIR 1:19,100

1. *Carex lacustris*--red tones with greenish tinge to them; pitted texture.
2. Degraded *Carex lacustris*--red and green mottled tones with patches of *Lemna minor* mixed in; coarse textured.
3. *Carex stricta*--bright red tones; very fine texture.
4. Degraded *Carex stricta*--red clumps surrounded by *Lemna minor* (flat textured, pinkish toned vegetation).
5. Transition--deep green tones with scattered red tones; coarse pitted texture.
6. Degraded transition--greenish red tones with much interspersion; fine textured.
7. Emergents--very green tones; coarse textured; often clonally shaped.
8. *Typha latifolia*--most deep, intense, true red on airphoto with a medium coarse texture. Usually areas of open water nearby.
9. *Scirpus fluviatilis*--rosy red tones, with medium coarse texture located along the forest on the far side of the stream.
10. *Spiraea alba*--deep red brown tones; a definite tuft texture.
11. Shrubs--deep red tones; a definite round shape creating a very coarse texture.
12. Weedy annuals--pinkish red areas with *Lemna* mixed in; medium texture.
13. *Lemna minor*--very bright pinkish white areas; smooth textured.
14. Open water--deep green, black tones.
15. Shrub carr--bright red tones; very coarse tufted texture, southo f the outflow channel.
16. Trees--bright and deep red tones with a very coarse texture.

September 24, 1976 CIR Scale 1:19,100

1. *Carex lacustris*--pinkish green areas along dike; fine texture.
2. Degraded *Carex lacustris*--blue-green and red dots surrounded with pinkish white *Lemna minor*; medium texture.
3. *Carex stricta*--deep red; fine textured clones along dike and out in the center of the study site south of the keyhole well.
4. Degraded *Carex stricta*--red tussocks (dots) surrounded with pinkish white *Lemna minor*; medium texture.
5. Transition--deep green tones mottled with red; pitted texture.
6. Degraded transition--greenish areas with much interspersion; medium coarse textured.
7. Emergents--deep green tones; coarse texture; some distinctive clones.
8. *Typha latifolia*--deep red-brown colored clones; coarse textured areas.
9. *Scirpus fluviatilis*--brown-red area against forest; coarse textured.

Table G-1. Continued

| Interpretation Keys |
|---|

10. *Spiraea alba*--very fine tufted texture; mottled red-khaki tones.
11. Shrubs—pink and red tones; very coarse textured; visible round crowns.
12. Weedy annuals--pinkish white areas with scattered sparse vegetation.
13. Floating mat--whitish, flat textured areas with sparse vegetation.
14. *Lemna minor*--pinkish white areas; a smooth, solid appearing texture.
15. Open water--deep green-blue black tones with a smooth texture.
16. Trees--rosy red tones with coarsest texture on the photograph.

June 25, 1977 CIR Scale 1:38,200

1. *Carex lacustris*--reddish, fine textured; sparse scattered clones in south end of study site.
2. Degraded *Carex lacustris*--deep red and rust tones with light pinkish tones of *Lemna minor* mixed in; fine texture.
3. *Carex stricta*--deep rosy tone; dense vegetation; fine texture.
4. Degraded *Carex stricta*--open areas with bright red clumps and scattered pink-white tones; pitted textures.
5. Transition—pink toned areas dissected with water and scattered *Lemna minor*.
6. Degraded transition--greenish areas with much interspersion and *Lemna*.
7. Emergents—deep red-brown tones; medium texture.
8. *Typha latifolia*--bright deep red tones; medium texture.
9. *Scirpus fluviatilis*—very intense pink areas with medium coarse texture against forest behind stream.
10. *Spiraea alba*—brownish-red tones with a coarse tufted texture.
11. Shrubs—deep red-pink; distinct rough shape; scattered throughout study site, along dike and along overflow channel.
12. Weedy annuals--light bluish pink toned areas containing sparse vegetation.
13. Floating mat--blue-greenish white areas along areas of open water.
14. *Lemna minor*—light pink toned areas containing very sparse vegetation.
15. Open water--blue black tones; smooth texture.
16. Shrub carr--coarse textured, deep magenta tones in area south of overflow channel near south knoll.
17. Trees--deep red magenta tones; most coarse texture in scene; tree crowns very distinctive.

June 25, 1977 Color Scale 1:38,200

1. *Carex lacustris*—deep green tone; smooth fine texture.
2. Degraded *Carex lacustris*—large mottled tannish areas; fine texture.
3. *Carex stricta*—medium green; fine textured.
4. Degraded *Carex stricta*--brownish areas; fine texture.
5. Transition--deep green and brown tones with much interspersion.

Table G-1. Continued

Interpretation Keys

6. Emergents--mottled deep green toned areas with a medium coarse texture at back of site.
7. *Typha latifolia*--deep green clones; fuzzy textured.
8. *Scirpus fluviatilis*—intense deep green tones with medium texture; along forest.
9. *Spiraea alba*--green areas with a coarse texture.
10. Shrubs—coarse textured green areas—difficult to see unless a number of them exist together.
11. Weedy annuals--mottled green-white areas, fine textured.
12. Floating mat--brownish green areas adjacent to open water in center of scene.
13. *Lemna minor*--bright chartreuse green; smooth textured.
14. Open water--deep green and muddy brown tones.
15. Shrub carr--coarse textured green area near the south knoll.
16. Trees—very deep, forest green tone with coarsest texture on the airphoto.

October 3, 1977 Scale 1:11,500

1. *Carex lacustris*--deep greenish pink toned clones in south end of study site; fine textured.
2. Degraded *Carex lacustris*--whitish pink areas with much interspersion; fine textured.
3. *Carex stricta*--visible greenish tussocks.
4. Degraded *Carex stricta*--green toned tussocks surrounded by *Lemna minor*.
5. Transition--green toned areas mottled with red; some interspersion; texture medium.
6. Emergents--blue-green and green tones; clone shaped areas; coarse textures.
7. Degraded emergents--mostly water cress with sparse emergent vegetation.
8. *Scirpus fluviatilis*—large, medium coarse textured reddish-green clone to back of study site.
9. *Spiraea alba*—coarse textured, deep russet-red areas out along the overlow channel.
10. Shrubs--quite reddish tones; individual round crowns visible throughout study site.
11. Weedy annuals--water and interspersed sparse vegetation.
12. Floating mat—large scattered pink tones; areas with coarse texture and much interspersion.
13. *Lemna minor*--light pink toned, flat textured areas.
14. Open water--deep blue tones; smooth texture.
15. Shrub carr--area south of overflow channel-brown-green red tones with coarse texture.
16. Trees--pink-red tones; coarsest texture; individual tree crowns visible.

# APPENDIX H

## ANNOTATED BIBLIOGRAPHY

### REMOTE SENSING--GENERAL INFORMATION

Ashley, M. O., W. W. Knapp, and J. Rea. 1974. Phenological Data From the ERTS-1 Satellite. In: Proceedings of the 2nd Canadian Symposium on Remote Sensing. Guelph, Ontario. p. 662-667.

The analysis, procedures, and results of research utilizing Earth Resources Technology Satellite multispectral scanner data to study phenological or seasonal changes in forest, crop, and range vegetation are discussed. This study was undertaken by a multidisciplinary group of researchers working with data from several areas of the United States. Visual imagery interpretation, band-to-band density ratios and computer generated band ratio parameters are used to show local and regional phenological events for the 1972-1973 fall recession and spring progression of vegetation development. Image density measurements put in ratioform using band 5 (red wavelengths) and band 7 (near infrared wavelengths) imagery correlate well with forest vegetation changes documented by ground observation photography. This ratio $\frac{\text{Band 7 - Band 5}}{\text{Band 5 + Band 7}}$ is lowest with leaf off and steadily increases with leaf development. Typical values are 0.08 for leaf off to 0.26 for full leaf in mid-summer. Band ratio parameters calculated from reflectances recorded on the scanner's computer computable tapes are also shown to be well correlated with these developments. This ratio $\frac{\text{Band 7 - Band 5}}{\text{Band 7 + Band 5}}$ follows the same pattern as the density ratio. Visual interpretations of positive transparencies indicated a decreasing red reflectance and increasing infrared reflectance with vegetation development. Conclusions are that phenological events for crops, forest, and range land can be predicted through visual interpretation, image density measurement and computer calculated reflectance methods.

Aldred, A. H. 1972. Decisions on Combining Data From Several Sensors. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 681-690.

The purpose of the paper is to set up a cost effectiveness model for evaluating the efficiency of combining information collected from satellite imagery, large-scale photos and ground measurements. A forest inventory problem is used to illustrate the approach and to indicate the cost advantages of using more than one imaging medium for certain problems. Some criteria are given for deciding when to use multiple sources of image data.

Allen, W. A., H. W. Gausman, A. J. Richardson, and C. L. Wiegand. 1970. Mean Effective Optical Constants of Thirteen Kinds of Plant Leaves. Applied Optics 9:2573-2577.

Plant leaves grown in a greenhouse and leaves collected from the field have been analyzed to obtain mean effective optical constants based upon diffuse reflectance and transmittance measurements taken over the 0.5-2.5- spectral range. These optical constants are used in a generalized flat-plate model to describe the phenomena of leaf reflectance. The analytical procedures that were developed led to measurement of the amount of water and intercellular air spaces in the leaves. Over the 1.4-2.5 spectral range, the adsorption spectra o leaves are not statistically different from that of pure liquid water. Leaf reflectance differences among the plant leaves over the 0.5-1.4 range are caused principally by Fresnel reflections at external and internal leaf surfaces and by plant pigment absorption. Reflectance over the 1.4-2.5 ) range results largely from Frenel reflections and adsorption by water. Data are presented in the form of dispersion curves with 95% confidence bands and tabulated plant leaf t adsorption spectra. The dispersion curves were assumed to be cubic equations of the form a , (i = 0, 1, 2, 3), where is wavelength. Reflectance measurements at 1.65 have been associated with the equivalent water thickness and the intercellular air spaces in the leaf. Accuracy of the plate theory based upon a cubic dispersion curve is shown to be within experimental error.

Anson, Abraham. 1966. Color Photo Comparison. Photo. Eng. 32:286-297.

This article is the result of action by the Color Photography Committee of the American Society of Photogrammetry in which panchromatic, color and Ektachrom IR photography of the same area were compared under essentially identical conditions. The study includes the identification and interpretation of drainage, vegetation, soils, and map features such as roads, railroads, and buildings. As a control the same features were identified on the ground. In addition, the photointerpreters were required to identify 42 selected photopoints that appeared in photographs. On the basis of the limited study, Ektachrome IR photography proved to be superior to both color and panchromatic photography for mapping, vegetation, and drainage. Color photography was found to be superior to panchromatic and Ektachrome IR for mapping soils and culture.

Ballard, R. J., and L. F. Eastwood, Jr. 1977. Estimating Costs and Performance of Systems for Machine Processing of Remotely Sensed Data. In: Fourth Annual Symposium on Machine Processing of Remotely Sensed Data. LARS, West Lafayette, Indiana. p. 208-214.

This paper outlines a method for estimating computer processing times and costs incurred in producing information products from digital remotely snesed data. The method accounts for both computation and overhead, and it may be applied to any serial computer. The analysts apply the method to estimate the cost and computer time involved in producing Level II Land Use and Vegetative Cover Maps for a five-state, midwestern region. Their results show that the amount of data to be processed overloads some computer systems, but that the processing is feasible on others.

Barry, F. K., and J. A. Smith. 1977. An Overview of Vegetation Canopy Modelling for Signature Correction and Analysis. In: Fourth Annual Symposium on Machine Processing of Remotely Sensed Data. LARS, West Lafayette, Indiana. p. 194.

Modeling of the interaction of solar radiation with vegetation canopies offers a tool for sensor design, signature extension, and relating intrinsic scene parameters to composite scene response. Theoretical approaches include both the deterministic solution of a system of simultaneous differential equations and Monte Carlo Modeling which treats the canopy as consisting of layered statistical ensembles of foliage elements against a soil background. In this paper the authors discuss several applications of canopy modeling to the general problem of understanding and correcting signature variations. Discussion will emphasize a Monte Carlo model that was originally developed to investigate the bidirectional reflectance character of natural grasslands. Subsequently, as part of the Large Area Crop Inventory Experiment, the model was used to analyze wheat reflectance dependence on both diurnal and crop development variation. LANDSAT response was simulated by interfacing the canopy reflectance model with an atmospheric radiation transfer model. The combined model predictions were used to develop correction coefficients for sun angle effects in wheat and to investigate signal variations induced by soil brightness. Research into the feasibility of utilizing model-derived data to infer intrinsic scene variables through divergence classification was also conducted. The model is currently being modified for forest canopies to study scene mixture and sun angle effects in this context.

Bauer, Kenneth G., and John A. Dutton. 1962. Albedo Variations Measured From an Airplane Over Several Types of Surface. J. of Geophys. Res. 67(6):2367-2376.

Albedo values for four different types of terrain were observed at semiregular intervals over south-central Wisconsin from October 1959 to July 1960 with instruments mounted on a light twin-engined aircraft. It was found that albedo has only two basic seasonal vaues--snow or no snow. Values between 10 and 20 percent were observed over agricultural land areas in snow-free seasons. With snow, the albedo values were as high as 80 percent over a frozen lake and as low as 50 percent over wooded hills. The instrument installation is discussed and it is shown how a "beam" system may be calibrated against a hemispherical system. Measured data from both systems then agreed over land. Within 1,000 ft of the ground, the measured albedo decreased less than 5 percent. Data on cloudedge effects, on albedo changes observed during descent through a cloud layer, and on the albedo of a lake preceding the spring breakup of the ice cover are presented.

Beckett, P. H. T. 1972. The Statistical Assessment of Resource Surveys by Remote Sensors. In: Environmental Remote Sensing: Applications and Achievements. Eric C. Barrett and Leonard F. Curtis, eds. Crane & Russak, New York. p. 11-27.

Published discussions on the use of remote sensing procedures for obtaining information about natural resources or the environment contain many unsupported value judgments (e.g., "better than", "more information than").

The utility of remote sensing procedures should be assessed on the truth and precision of the information (statements) they provide, and the costs of obtaining it. This paper lists the kinds of statement which may be required from remote sensors, and offers a preliminary review of methods for judging the success of remote sensors in providing them. The same methods may be used for the quality control of resource surveys by remote sensors, performed under contract.

Blanchard, Bruce J., and Ross W. Leamer. 1973. Spectral Reflectance of Water Containing Suspended Sediment. In: Remote Sensing and Water Resources Management, Proc. No. 17. p. 339-347.

A spectral radiometer, measuring radiation in the visible and near-infrared portion of the spectrum, was used to examine (1) different concentrations of red, black, and gray clay particles in water, and (2) several samples of natural pond water containing sediment. Four of the pond samples had algae present. Density measurements were made of color and color infrared film photographs of the sample exposed at the same time as the radiometer measurements. Reflectance curves in the near-infrared region show very little change caused by changing sediment concentrations. However, reflectance curves in the visible portion of the spectrum are sensitive to very low concentrations (less than 200 ppm suspended solids) of sediment with similar characteristics. The samples containing algae showed a good possibility of detecting algae by ratioing the reflectance near wavelength 570 nm with the reflectance at 680 nm. Response at 570 nm appears to be related to the suspended sediment. Results using the film density measurements also show promise for use in estimating low sediment concentrations; however, the best combination of film and filter are not known for the different sediment characteristics. (KEY TERMS: Sediment, remote sensing, spectra, reflectance, visible light, near-infrared, water quality.)

Bogard, Jacqueline A. 1974. A Comparative Analysis of Remote Sensing Imagery for Vegetation Studies. 50 p. For: CEE 552, University of Wisconsin.

Remote sensing has been recognized as a valuable tool for vegetation studies. A considerable amount of research has been done to determine which sensing system is optimal for particular plant formations. Although every type of imagery reviewed in this paper possesses certain inherent advantages, color and color infrared have the widest range of capabilities. I found, however, that the inexpensive panchromatic photographs (scale 1:20,000) from the surveys of the Agriculture Stabilization and Conservation Service provided a valuable data source for monitoring land use and vegetation patterns over time.

Buchanan, Warren J. 1978. Applications of Digitized Film Analyses and Perceptions of Possible Users. M.S. Thesis, University of Wisconsin-Madison, Madison, Wisconsin. 147 p.

70mm color infrared transparencies of upland and lowland resource complexes were digitized with a drum-type scanning microdensitometer. The effects of seasonal change and resolution on digital signature behavior were investigated along with signature extendability, classification accuracy, time and cost efficiency of resource classification. Seasonal studies indicated that, for digital analysis, at least some signatures were confounded in all seasons, but these confounded signatures shifted through the growing season such that a combination of seasonal data would successfuly separate nearly all resources. As the resolution cell increased in size from 0.25 m to 14.59 m , the resource signatures decreased in width and became more discrete; however, linear resources such as roads were unresolved with the largest resolution cell. Signatures appeared to be extendable from image to image if images were: 1) from the same roll of film; 2) were processed the same; 3) were exposed within a short time span; 4) were corrected and calibrated the same; and 5) were scanned at the same time. The best classification accuracy achieved was 85% until these advantages are repeatedly verified, demonstrated, and documented, the growth of this technology will probably be gradual at best. Problems such as unfamiliariy or inaccessibility can be overcome simply by increasing awareness of existing facilities. The acceptance of digitized film analysis will always behindered by its perceived disadvantages: expense and inaccuracy.

Carter, P., and W. E. Gardner. 1977. An Image-Processing System Applied to Earth-Resource Imagery. In: Environmental Remote Sensing. E. C. Barrett and L. F. Curtis, eds. p. 143-162.

The Harwell Image Processing System (HIPS) has been adapted for processing earth-resource imagery in either film or tape format. Data from film is obtained using a computer-controlled flying-spot scanner. Local rapid interactive processing is based on a PDP 11/20 mini-computer which has suitable display facilities for immediate visual appraisal of results and also a fast data link to an IBM 370/168 computer complex. An extensive subroutine library is being assembled for data preprocessing and feature extraction. This chapter includes a discussion of the basic principles of image analysis, a description of the HIPS system, and finally, for illustrative purposes, a description of several simple software routines.

Clegg, Robert H. 1975. Accuracy, Resolution and Cost Comparisons Between Small Format and Mapping Cameras for Environmental Mapping. In: Proceedings of the American Society of Photogrammetry, 41st Annual meeting. Washington, D.C. p. 663-691.

Successful aerial photography depends on aerial cameras providing acceptable photographs within the cost restrictions of the job. For topographic mapping, where the ultimate accuracy is required, only large format mapping cameras will suffice. For mapping environmental patterns of vegetation, soils, or water pollution, 9-inch cameras often exceed accuracy and cost requirements, and small formats may be better. In choosing the best camera for environmental mapping, relative capabilities and costs must be understood. This study compares resolution, photo interpretation potential, metric accuracy, and cost of 9-inch, 70 mm, 35 mm cameras for obtaining simultaneous color and color infrared photography for environmental mapping purposes.

Clouston, John G. 1950. The Use of Aerial Photographs in Range Inventory Work on the National Forests. Photo. Eng. 16:320-331.

The use of aerial photographs in making range inventories is described. The author believes that use of airphotos greatly increases the accuracy of such inventories since they clearly define range types and make type checking easier.

Collins, S. H. 1972. The Block Adjustment of Colour in High-Altitude Photography. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 659-575.

This paper describes a complete program of density calibration for color and multispectral high-altitude photography. The central technique is a "block adjustment" of colour, considered as a multi-dimensional variable, over a complete block of frame photography; in a manner analogous to the block adjustment of point location in analytical photogrammetry. The images of selected ground areas are located in the overlaps between frames and between flight-lines. The colours of these "pass points" are used to determine correction functions for colour variations that occur within and between frames throughout the roll. The part of the sun-angle effect which is due to the nature of the terrain is suggested as a powerful discriminant for automatic photointerpretation. A method is also described for the absolute calibration of the whole block for ground radiance. The method is photographic, and it ties the radiance values to a great variety of known terrain and cover types on a regional basis. The value of this work in providing comprehensive ground truth for satellite imagery over a large region is discussed.

Colewell, R. N., and D. L. Olson. 1964. Thermal Infrared Imagery and Its Use in Vegetation Analysis by Remote Aerial Reconnaissance. In: Proceedings of the Third Symposium on the Environment. Ann Arbor, Michigan. p. 607-621.

In recent years it has become acutely apparent that from both the military and civil standards, there is a need for some rapid, accurate and economical means of analyzing vegetation. This paper will consider the various kinds of useful information which military and civil experts can obtain regarding vegetation from the use of a thermal infrared mapping system which operates in the 7-15 micro band. Special emphasis will be placed on the value of this imagery when used in conjunction with imagery obtained in the visible, near infrared, and near ultraviolet portions of the electromagnetic spectra.

Colwell, John E. 1974. Vegetation Canopy Reflectance. Remote Sensing of the Environment 3:175-183.

Possible cause-effect relationships in producing vegetation canopy reflectance are discussed. Hemispherical reflectance and even bidirectional reflectance measurements are shown to be inadequate for predicting or understanding vegetation canopy relfectance in many situations. Among the additional important parameters necessary for prediction and understanding of vegetation canopy reflectance are leaf hemispherical transmittance, leaf area and orientation, characteristics of other components of the vegetation canopy (stalks, trunks, limbs), soil reflectance, solar zenith angle, look angle, and azimuth angle. The effects of these parameters on vegetation canopy bidirectional spectral reflectance are described.

Conn, Jeffery S., Kenneth C. Foster, and William G. McGinnies. 1975. The Nature of Spectral Signatures in Native Arid Plant Communities. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Phoenix, Arizona. p. 876-883.

Radiometric data in ERTS bands 5 and 7 of spectral signature components were compared to the overall signatures obtained from an airborne radiometric data collection system flown at low altitude. Results indicate that due to the low density and low vigor of the vegetation, vegetation has little effect on the overall signature, thus making differentiation of desert plant communities on the basis of spectral signature extremely difficult.

Cooper, Charles F. 1964. Potential Applications of Remote Sensing to Ecological Research. In: Proceedings of the 3rd Symposium on Remote Sensing of the Environment. Ann Arbor, Michigan. p. 601-606.

Field investigations of the behavior of natural plant communities require knowledge of physical and biological characteristics integrated over areas of a few square feet to several square miles. Important properties potentially measurable by remote sensing techniques, singly or in combination, include leaf area, volume, weight, and chlorophyll content of vegetation; heat budgets of vegetated surfaces; qualitative and quantitative local differences in water vapor and carbon dioxide fluxes; water content of soils and vegetation; and depth and density of snow. Some implications of these measurements for understanding of ecological processes are discussed. Close collaboration between instrumentation engineers and field biologists is essential if best results are to be obtained.

Cox, T. L., H. C. Hitchcock, and S. G. Weber. 1975. Processing of Remotely Sensed Data for Dimensional Analysis. In: Symposium Proceedings of Machine Processing of Remotely Sensed Data. LARS, West Lafeyette, Indiana. p. 18-37--18-44.

Forest inventory data was interpreted from color IR photography, transferred to base maps, and digitized for machine processing. The data was registered to geodetic coordinates providing the capability to perform several types of dimensional analysis. Processing data by this technique allowed: (1) spatial or single variable analysis, (2) overlay or composite analysis (in combination with other variables), and (3) temporal analysis. Information derived from this procedure was input for a land management decision system used to construct a forest management plan for 25,000 acres in east Tennessee.

Cummings, Robert, and Robert R. Jayroe, Jr. 1973. Unsupervised Classification Techniques as Components of a Data and Information System. In: Am. Soc. of Photogrammetry Symposium Proceedings, Mngt. & Utilization of Remote Sensing Data. Sioux Falls, S.C. p. 248-256.

The phenomenal increase in the amount of data and information being generated by remote sensing systems is stressed. A total system design approach as a solution to this problem is discussed with specific reference to the data and information system needs for Sortie Lab--a multiple use payload for the Shuttle. The development of a multispectral data processing system as a needed component of such a system is reviewed with emphasis on unsupervised classification techniques developed and presently in use at Marshall Space Flight Center.

Curtis, L. F. 1977. Ground Monitoring for Airborne and Space Sudies of Land Use and Soil Conditions. In: Environmental Remote Sensing. E. C. Barrett and L. F. Curtis, eds. Edward Arnold, London. p. 192-215.

Published discussions on the use of remote sensing procedures for obtaining information about natural resources or the environment contain many unsupported value judgments (e.g., "better than", "more information than"). The utility of remote sensing procedures should be assessed on the truth and precision of the information (statements) they provide, and the costs of obtaining it. This paper lists the kinds of statements which may be required from remote sensors, and offers a preliminary review of methods for judging the success of remote sensors in providing them. The same methods may be used for the quality control of resource surveys by remote sensors, performed under contract.

Derenyi, Eugene E. 1972. Geometric Considerations in Remote Sensing. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 547-550.

In order to judge the potentials of image-forming remote sensors properly, both the spectral characteristics and the geometric aspects must be considered. With respect to the latter one, two factors are of primary importance: (1) Geometric or spatial resolution which, in the case of an optical mechanical scanner, is a function of the instantaneous angular field of view and for a radar system depends on the accuracy of the time measurement, on the slant range and on the beam width. (2) Geometric fidelity, which is influenced by the inherent distortions of the sensor, distortion characteristics of the photographic material, terrain and environmental conditions, and by fluctuating in the attitude, altitude and velocity of the airborne vehicle carrying the sensor. Both factors are discussed in detail. From a geometric point of view, the performance of unorthodox image forming sensors is inferior to that of modern frame camera systems. Results of a theoretical investigation and of a test conducted on infrared scanner imagery are presented as a proof. The use of stabilized platforms and analytical or analogue image restitution is suggested to improve the geometric fidelity of dynamic imagery.

El-Baz, F. 1978. The Meaning of Desert Color in Earth Orbital Photographs. Photo. Eng. 44(1):69-75.

The color of desert surfaces as seen in Earth orbital photographs is indicative of soil composition. Apollo-Soyuz photographs of the Sturt and Simpson Deserts of Australia confirm that sand grains become redder as the distance from the source increases. Reddening is caused by a thin iron-oxide coating on individual sand grains and can be used, in some cases, to map relative-age zones. Photographs of the Western (Libyan) Desert of Egypt indicate three distinct and nearly parallel color zones that have been correlated in the field with: (1) arable soil composed of quartz, clay, and calcium carbonate particles; (2) relatively active sand with or without sparse vegetation; and (3) relatively inactive sand mixed with dark (desert-varnished) pebbles. The youngest sands are in the form of longitudinal dunes, which are migrating to the south-southeast along the prevailing wind direction. Some of the young dune fields are encroaching on the western boundary of the fertile Nile Valley.

Friederichs, G. A., and F. L. Scarpace. 1977. A Method of Determining Spectral Dye Densities in Color Films. In: Proceedings of the Am. Soc. of Photogrammetry, 43rd Annual Meeting. Washington, D.C. p. 257-279.

A straight forward method for the user of color imagery to determine the spectral density of the dyes present in the processed imagery is presented. The method involves exposing a large number of different color patches on the film. The number of different patches necessary to span the gamut of the film's imaging capabilities has been investigated. From integral spectral density measurements at sixteen different wavelengths, the unit spectral dye curves for each of the three dyes present were determined. The spectral density measurements were subjected to a characteristic vector analysis which determined a set of eigenvalues and eigenfunctions for the set of exposed color patches. The best linear combinations of the eigen vectors fit to the published spectral dye curves were determined to be the spectral dye densities of the film after processing. A discussion of the use of these spectral dye densities to determine the transformation between integral density measurements and analytical density is presented.

Fritz, Norman L. 1967. Optimum Methods for Using Infrared-Sensitive Color Films. Phot. Eng. 33:1128-1138.

Considerable interest has currently been expressed in the potential of Kodak Ektachrome Infrared Aero Film, Type 8443, as a remote sensor for applications as diverse as aerial reconnaissance and the detection of diseases and pests in agricultural crops. The results obtained with this film can be optimized through a knowledge of some of its special characteristics, and by using photographic techniques which take advantage of its unique properties. Consideration of the typical scene characteristics indicates that the principal applications at the present time involve the photography of foliage. By observing appropriate methods for storing, exposing and processing, one is assured of obtaining photographs having the highest information content.

Gausman, H. W., et al. 1978. Distinguishing Succulent Plants from Crop and Woody Plants. Photo. Eng. 44(4):487-491.

The analysts compared laboratory spectrophotometrically measured leaf reflectances of six succulents (peperomia, possum-grape, prickly pear, spiderwort, Texas tuberose, wolfberry) with those of four nonsucculents (cenizo, honey mesquite, cotton, sugarcane) for plant species discrimination. Succulents (average leaf water content of 92.2 percent) could be distinguished from nonsucculents (average leaf content of 71.2 percent) within the near-infrared water adsorption waveband (1.35 to

2.5 m). This was substantiated by field spectrophotometric reflectances of plant canopies. Sensor bands encompassing either the 1.6- or 2.2- m wavelengths may be useful to distinguish succulent from nonsucculent plant species.

Gausman, H. W. 1977. Reflectance of Leaf Components. Remote Sensing of Environ. 6:1-9.

The reflectance of leaf components was evaluated over the 370 to 1100 nm wavelength interval. Kodak high speed, black-and-white infrared photographs at 850 nm showed that: (1) Leaf epidermises of Elodea (Anacharis canandensis, Planch.) and Lemna L. diffused incoming infrared light; (2) infrared light was reflected from surfaces inside leaves of Rhoeo discolor Hance, through stomatal apertures; and (3) crystals and chloroplasts in the expressed sap of Zebrina pendula Schnizl. reflected infrared light. Scans (370 to 1100 nm) showed that reflectance from complex cell walls of Aqavae americana L. compared with that of the adjacent cytoplasm was significantly greater ($p = 0.01$) than the reflectance of simpler cell walls of Heliconia humile L. compared with that of the adjacent cytoplasm. The reflectance of Vicia faba L. nuclei was larger (significant, $p = 0.10$) than that of adjacent cell areas. Results show that refractive index discontinuities in leaves cause the reflectance of near-infrared light.

Goodenough, David, and Seymour Shlien. 1974. Results of Cover Type Classification by Maximum Likelihood and Parallelepiped Methods. In: Proceedings, 2nd Canadian Symposium on Remote Sensing. Gueleph, Ontario. Vol. I. p. 135-164.

This paper describes the results of automatic ground cover classification utilizing the spectral intensities of ERTS-1 images. The methodology used for the interactive software classifier has been described in the preceding paper (Shlien and Goodenough 1974). The classifier was used to distinguish crops and different types of vegetation and water in Manitoba and Ontario. The results are presented in the form of colour photographs showing regions before and after classification. The effects of ratioing and radiometric calibrations on the classifications are also visually presented. The accuracies of the classification are discussed. The lowest classification accuracies occurred with crop identification.

Grinnell, H. Rae. 1972. The Economics of Remote Sensing of Forest Land. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 691-696.

The output of remote sensing systems are discussed in terms of economics, early development and effective use in Canada. Opportunities to increase benefits from current systems depend on clear objectives for the multiple use of a limited number of image resolutions derived at specific time intervals. The frationated incomplete photo coverage of Canada and the low unit cost of standardized scales are suggested as ample reasons to bring about some rationalization of the current multi-view approach to resource surveying in Canada.

Gustafson, T. D., and M. S. Adams. 1974. Remote Sensing of Myriophyllum Spicatum L. in a Shallow, Eutrophic Lake. In: Remote Sensing and Water Resources Mngt., Proc. No. 17, Am. Water Resources Assoc. p. 387-391.

An aerial 35 mm system was used for the acquisition of vertical color and color infrared imagery of the submergent aquatic macrophytes of Lake Wingra, Wisconsin. A method of photographic interpretation of stem density classes is listed for its ability to make standing crop biomass estimates of Myriophyllum spicatum. The results of film image density analysis are significantly correlated with stem densities and standing crop biomass of Myriophyllum and with the biomass of Oedogonium mats. Photographic methods are contrasted with conventional harvest procedures for efficiency and accuracy. (KEY TERMS: Myriophyllum; Oedogonium; Aquatic Macrophytes; Biomass; Water quality; Eutrophication; Limnology; Ecology; Color, color infrared aerial photography.)

Hallert, Bertel. 1970. Calibration and Tests of Hasselblad EL-Data Camera No. 12123. In: 1970 International Symposium on Photography and Navigation. Columbus, Ohio. p. 309-327.

The new Hasselblad-Hallert camera, used during the latest moon expeditions, has been carefully tested and calibrated in accordance with I.S.P.-resolutions and recommendations. The photographs in black-and-white as well as in color have been found to have excellent geometrical qualities. The quality of the final results of analytical and analogue stereoscopic restitution is in full agreement with theoretically expected data as determined from the basic quality of image coordinates and y-parallax measurement. The camera can be expected to be of the greatest value for terrestrial and aerial photogrammetry.

Hansen, Jack H. 1973. Color and Color Variation of a Hardwood Forest as Imaged on Color Infrared Film. In: Proceedings of the Am. Soc. of Photogrammetry, 39th Annual Meeting. Washington, D. C. p. 326.

Techniques for measuring and methods of describing color and color differences of imaged objects on color transparencies are explained. The measurement of the transmittance of imaged objects is done on a Leitz MPV microscope photometer equipped with an in-line monochrometer. From these measurements the internal transmittance of the three dye layers is calculated at 10 nanometer intervals from 380 to 720 nanometers. CIE (Commission Internationale de l'Eclairage) approved methods are used to define the imaged object's color by three approved systems and the paired color differences between all objects are calculated. A multiple comparison test yielded predictions that are correct for 119 out of 120 pairs of comparisons possible for the 16 objects studied on the 1/3,000 scale infrared transparencies.

Hardy, Rolland L., and J. V. Taranik. 1973. Geodesy, Photogrammetry, Photointerpretation and Remote Sensing--Getting It All Together in Earth Mapping Education. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on the Management and Utilization of Remotely Sensed Data. Sioux Fall, South Dakota. p. 501-511.

Iowa State University and The University of Iowa now offer a coordinated interdisciplinary program in imagery interpretation, photogrammetry, geodesy, and remote sensing. This interdisciplinary program has evolved because of the rapid development of space technology and sensor instrumentation. There is a growing need for engineers and scientists to have a broad background in earth mapping technology. Photogrammetrists now use imagery from multispectral scanners and video imagers mounted in spacecraft. Photointerpreters must now evaluate imagery from radar imagers and line scanners, and to understand the taxonomic characteristics of imagery and to properly evaluate imagery artifacts, they must understand the spectroradiometric characteristics of the energy path from source to detector. Scientists engaged in remote sensing programs must understand how to mensurate and interprete imagery, as well as design remote sensing and analysis procedures. Educators at Iowa State University and The University of Iowa have recently joined forces to offer a combined course of study for students with interests in mapping the earth from aircraft and spacecraft. Prior to the new program, photogrammetry and geodesy were taught in the Civil Engineering Department at Iowa State University, remote sensing in the Geology Department at The University of Iowa, and photointerpretation in different departments at both universities. Often a student with interests in earth mapping outside his major department would have difficulty taking courses in other departments or other universities. Under the new program, students and faculty are exchanged between universities and departments, and those engaged in research can utilize facilities and equipment at either university. The recent development of a state remote sensing laboratory, which serves the needs of 24 state and federal agencies operating in Iowa, provides impetus for the interdisciplinary educational program because it repeatedly brings together basic researchers from the academic community, analysts of imagery and those applying the analyses to the practical problems of natural resource management, land utilization planning, and environmental control in Iowa.

Heller, R. C. 1978. Case Applications of Remote Sensing for Vegetation Damage Assessment. Photo. Eng. 44:1159-1166.

The assessment of vegetation damage by remote sensing has reached a fairly sophisticated level. This paper identifies the advantages, pitfalls, current practical applications, and future possibilities of the use of remote sensing for this purpose. Advantages include: (1) the use of many parts of the electromagnetic spectrum; (2) the saving of time, money, and manpower; (3) the ability to cover large areas; and (4) the use of successive remote sensing surveys to follow damage trends. Some pitfalls included: (1) the overselling of remote sensing techniques without adequate quantitative data showing errors of estimate at pre-defined confidence limits; (2) using very expensive remote sensing systems on a transitory phenomenon; (3) the inability of some Landsat users to recognize that reflectant values are relative subject to atmospheric attenuation, and amplified signals; (4) the poor design of Landsat wavebands for vegetation damage assessment (a yellow-orange waveband, 0.58 to 0.62 m is needed); (5) a need for better statistical techniques to check classification accuracies; and (6) using color or color infrared films to obtain previsual detection of coniferous tree damage. Current practical applications for assessing vegetation damage include: (1) visual observation techniques (sketch mapping and strip recording); (2) color and color infrared (CIR) photography (both large and very small scale) when properly matched with damage symptom, host type, and atmospheric conditions; (3) multi-stage sampling; and (4) risk rating systems using aerial photos to define factors such as aspect, slope, elevation, and stand density that contribute to susceptibility of vegetation to damaging agents. Future remote sensing possibilities predicted are (1) increasing standardization of color and CIR photography and greater use of small-scale CIR (1:32,000); (2) the availability of lightweight, inexpensive radar and laser altimeters together with better electronic guidance systems for repetitive flights; (3) faster service for receipt of Landsat data products which will be geometrically corrected and enhanced; (4) improved Landsat computer classified images with accuracy statements; (5) better resolution available on Landsat D (thematic mapper) with narrower wavebands which should improve classificatory procedures and accuracies; and (6) improvements in other sensors such as side-looking radar, charge coupled detectors, and microwave imagers.

Hoffer, R. M., P. E. Anuta, and T. L. Phillips. 1972. ADP Multiband and Multiemulsion Digitized Photos. Photo. Eng. 38(10):989-1001.

Automatic data processing (ADP) techniques using a digital computer for data handling and analysis have allowed quantitative examination of aerial photography. Scanning microdensitometer techniques were utilized to digitize both multiband and multiemulsion photography. These digital density data from 1:120,000-scale aerial photos were spatially registered by computer and then analyzed, using statistical pattern recognition algorithms. The feasibility for automatic recognition of several cover types is indicated. Similar results were obtained from the digitized multiband and multiemulsion photographic data.

Hornung, R. J., and J. A. Smith. 1973. Application of Fourier analysis to multispectral/spatial recognition. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on Management and Utilization of Remotely Sensed Data. Sioux Falls, South Dakota. p. 268-283.

One approach for investigating spectral response from materials is to consider spatial features of the response. This might be accomplished by considering the Fourier spectrum of the spatial response. The Fourier Transform may be used in a one-dimensional to multi-dimensional analysis of more than one channel of data. The two-dimensional transform represents the Fraunhofer diffraction pattern of the image in optics and has certain invariant features. Physically the diffraction pattern contains spatial features which are possibly unique to a given configuration or classification type. Different sampling strategies may be used to either enhance geometrical differences or extract additional features.

Hostrop, Bernard W., and T. Kawaguche. 1971. Aerial Color in Forestry. Photo. Eng. 37:555-563.

The most significant improvement in photogrammetry in recent years has been the introduction of aerial color photographs. At the same time, electronic printing of aerial negatives had enhanced the information content in reproducing both black-and-white and color materials. Color photographs play an important role in the development of areas for new timber harvest methods, soil and watershed studies, development of range and reforestation area, planning land development, and streambed and fish habitat studies. Color provides a signficant increase in accuracy of species identification, identification of dead trees, and facilitates the identification of property corners. Image-point selection and identification are improved by as much as 60 percent.

Howard, John A. 1970. Aerial-Photo Ecology. American Elsevier Publishing Co., New York. 325 p.

The reader is first introduced to the most important physical aspects of aerial photography, including the reflection of light; and is then given an adequate background of photogrammetry before proceeding to the general principles of photo-interpretation of the natural environment. Topics are discussed which will interest the agriculturalist, archaeologist, ecologist, entomologist, forester, game manager, geographer, geologist, geomorphologist, pathologist, physiologist, soil scientist and zoologist. The extensive bibliography from the nineteenth century until the end of the international congress on aerial photography, photogrammetry and photointerpretation in 1968 will be useful to workers in almost all fields where aerial photographs are used.

Hoyer, B. E., G. R. Hallberg, and J. V. Taranik. 1973. Seasonal Multispectral Flood Inundation Mapping in Iowa. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on the Management and Utilization of Remotely Sensed Data. Sioux Falls, South Dakota. p. 130-141.

Evaluation of multispectral imagery from three floods occurring at different times of the year in Iowa has indicated methods of mapping different times of the year in Iowa has indicated methods of mapping flood inundation several days after flood waters have returned to the main river channel. Cooperative study by the Iowa Geological Survey, Remote Sensing Laboratory and the U.S. Geological Survey, Water Resources Division, on flooding in three seasons, suggests that color infrared film would provide flood inundation data having the highest multiplicity of possible uses for floodplain management-planning in Iowa. Characteristics of infrared radiation, including the adsorption of photograhic infrared wavelengths by water, the reduced infrared reflectance of wet soils and stressed plant species, and the different reflective properties of snow and ice at infrared wavelengths, account for this film's wide application to midwestern flood mapping. Winter floods may be mapped by identifying ice remaining after flood recession. Most photographic imagery appears adequate for mapping winter floods, but color infrared imagery appears somewhat superior. Evaluation of imagery from mid-spring floods indicates that significant flooding may be mapped for at least five days following flood recession. Conventional photographic imagery is adequate for interpretation in bare fields, but flood inundation of immature crops, pasture, or forest is most adequately interpreted on infrared imagery. Late summer floods may be mapped for at least seven days following flood crest using color infrared imagery. Best flood inundation mapping was accomplished by multispectral color-additive viewing utilizing the blue and infrared bands. ERTS-1 satellite data has supported some of the basic conclusions of the low-altitude studies. The satellite imagery also allowed the rapid appraisal of the areal extent of flood inundation on a regional scale.

Humiston, Homer A., and G. E. Trisdale. 1973. A Peripheral Change Detection Process. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on the Management and Utilization of Remotely Sensed Data. Sioux Falls, South Dakota. p. 413-426.

A "Quick-Look" change detection function is discussed. The method incorporates an on-line image registration capability which is not only independent of relative orientation and scale but also eliminates the need for identifiable control points within the images. The presentation will include experimental results produced by a pilot model system. Television input and output functions for this system incorporate self-calibrations, enabling precision control of scan linearities as well as photometry.

Hyde, R. F., S. W. Bowand, and P. W. Mausel. 1977. ISURSL Levels Classification: A Low Cost Approach to Multispectral Data Analysis. In: Proceedings of the Symposium on Machine Processing of Remotely Sensed Data. LARS, Lafayette, Indiana. p. 322-331.

The Indiana State University Remote Sensing Laboratory (ISURSL) recognized that the promise of low-cost earth resource evaluation through machine-assisted processing of multispectral (MS) data has not been fully realized. In response to this problem the ISURSL has developed a complete low-cost system of processing MS data which minimized analysis time for both man and computer while simultaneously maximizing utilization of the data. The basis of the ISURSL classification algorithm, designated LEVELS CLASSIFIER, is identification of numeric boundaries located in multidimensional feature space which differentiate features of interest. Land use classes of interest to an analyst are described by the range of radiance (relative spectral response) levels which define these boundaries. The identification of levels boundaries which accurately defines an earth surface feature is accomplished through sophisiticated single and multidimensional histogram terrain analysis. This approach to multispectral data analysis has been shown to be cost effective and accurate in several applied research projects at ISURSL.

Kalensky, L., and D. A. Wilson. 1975. Spectral Signatures of Forest Trees. In: Proceedings of the Third Canadian Symposium of Remote Sensing. Edmonton, Alberta. p. 190-205.

Described are the field measurements of daylight radiation reflected upwards from the crowns of six tree species in visible and near-infrared frequencies of the electromagnetic spectrum. A portable mast and two permanent towers provided platforms for a spectroradiometer at a height of 3 to 5 m above the tree canopy. Each site was measured on at least two different dates between late June and September to account for variations in species phenological stages during the summer season. In addition, some of the species were measured in two different locations to account for differences in site conditions. Described are the instruments used for the measurement of incident and reflected daylight radiation, the field measurement technique and computational procedure. Presented are the reflectance data of tree species and their variations calculated from the field spectroradiometric data measured in the 1974 season. Their relevance for multispectral remote sensing and image interpretation is discussed.

Kasvoud, T. 1972. Can We Teach Computers to See? In: First Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 551-667.

The number of pictures obtained by satellites, from aerial photography, from bubble chambers, microscopes and so on is nearly unlimited. Ideally we would like this picture data to be analysed by computers. On specific but limited problems fair success has been achieved. Thus, bubble chamber pictures are processed in large numbers, several types of micro-biological objects are recognized by computers, attempts have been made to classify fingerprints, to recognize objects on aerial photographs, etc. By pooling the experience gained from successes as well as failures, the author tries to outline the requirements for a fairly general pattern recognition system which can be taught to recognize given objects in the pictures.

Kau, E. P., D. L. Ball, J. P. Basu, and R. L. Smelser. 1975. Data Resolution Versus Forest Classification and Modeling. In: Proceedings of the Symposium Machine Processing of Remotely Sensed Data. LARS, West Lafayette, Indiana. p. 1B-24--1B-36.

This paper examines the effects on timber stand computer classification accuracies caused by changes in the resolution of remotely sensed multispectral data. This investigation is valuable, especially for determining optimal sensor and platform designs. Theoretical justification and experimental verification support the finding that classification accuracies for low resolution data could be better than the accuracies for data with higher resolution. The increase in accuracy is construed as due to the reduction of scene inhomogeneity at lower resolution. The computer classification scheme was a maximum likelihood classifier.

Kie, Soon T., and D. J. Lewis. 1974. Optical Film Density Values From Color IR Photography for Wetland Soils Mapping. In: Proceedings of the 1974 Fall Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 323-331.

An attempt is made to analyze characteristics of optical film density from small scale color IR film for the purpose of soils mapping. Four hundred and one (401) sample spots were selected, and transmittance diffuse density values were measured for four filters using a Macbeth Transmission Densitometer. A CRD analysis of variance, a factor analysis and two different cluster analyses were conducted. The results indicate that 1) the three known soil groups cannot be discriminated using the cluster analyses, 2) only one common factor is retained by the factor analysis and it contributes approximately 85 percent to the total communality, and 3) classification of soil groups may be feasible by an adjusted computer mapping procedure.

Kiefer, Ralph W. 1970. Effects of Date of Photography on Airphoto Interpretation Using Color and Color-Infrared Films. In: Proceedings of the International Symposium on Photography and Navigation. p. 100-117.

More than 3000 exposures of color and color-infrared film on 35 mm format were taken of selected sites in Southern Wisconsin during 1969 from elevations of 2000 to 8000 feet above terrain. The subject matter includes rural terrain (cropland, grazing land, and woodland), lakes (showing weed and algae growth), and river flood plains (showing river flooding and subsequent crop damage). Certain intensive study sites were photographed on 20 different dates during the year. The striking changes in week-to-week at the intensive study sites are illustrated in this paper. Relevant ground-truth data of selected sites are included. The results of this research show that there are certain optimum dates during the year for the procurement of aerial photography for interpretive uses. The results also show that the optimum date of photography may not be the same for different interpretive uses.

Kiefer, Ralph W. 1969. Airphoto Interpretation of Flood Plain Soils. J. of the Surveying and Mapping Division. 93:119-139.

The use of aerial photographic interpretation techniques to estimate flood plain soil conditions has been described herein. Problem areas requiring futher study include: (1) The use of airphoto interpretation to aid in estimating flood frequency; and (2) the effects of the date of photography on the airphoto appearance of flood plain soils. New techniques of airborne remote sensing can be useful for flood plain soil studies. Imaging sensors such as infrared photography, color photography, infrared imagery, and side-looking airborne radar, as well as a number of nonimaging sensors, may prove very useful. In order to plan successfully for land use on flood plains, all available planning tools must be utilized. Planners and developers should be aware that much valuable information about flood plain soils can be obtained through aerial photographic interpretation studies.

Kirby, C L., D. Goodenough, D. Day, and P. Van Eck. 1975. Landsat Imagery for Banff and Jasper National Parks Inventory and Management. In: Proceedings of the 3rd Canadian Symposium on Remote Sensing. Edmonton, Alberta. p. 107-225.

Computer assisted classification of Landsat digital magnetic tapes of Banff and Jasper National Parks were done using the General Electric "Image-100" of the Canada Centre for Remote Sensing in Ottawa. Themes of pine, spruce and popular-shrub forest, water, snow and meadows were classified by their spectral signatures. From 70 to 80 percent of the four areas studied were classified with 80 to 90 percent accuracy using a supervised parallelepiped classification. Small training areas (50-100 km ) in each Landsat image were classified using this method as well as 1200 km areas on two Landsat images classified successfully at full resolution. The classifications produced were geometrically correct in color at a scale of 1:250,000 on an electron beam image inventory and in a National Park public education program. A limited number of Landsat photo-maps of Banff and Jasper Parks at a scale of 1:500,000 on color, and with national topographic map information on water resources and transportation, are available on request to the Northern Forest Research Centre.

Knipling, E. G. 1970. Physical and Physiological Basis for the Reflectance of Visible and Near Infrared Radiation from Vegetation. Rem. Sens. Environ. p. 155-159.

Knowledge of how solar radiation interacts with vegetation is necessary to interpret and process remote sensing data of agricultural and many natural resources. A plant leaf typically has a low reflectance in the visible spectral region because of strong adsorption by chlorophylls, a relatively high reflectance in the near-infrared because of internal leaf scattering and no adsorption, and a relatively low reflectance in the infrared beyond 1.3 because of strong, adsorption by water. The reflectance of a plant canopy is similar, but is modified by the nonuniformity of incident solar radiation, plant structures, leaf areas, shadows, and background reflectivities. Airborne sensors receive an integrated view of all these effects and each crop or vegetation type tends to have a characteristic signature which permits its discrimination. When disease and physiological stresses directly affect the reflectance properties of individual leaves, the most pronounced initial changes often occur in the visible spectral region rather than in the infrared because of the sensitivity of chlorophyll to physiological disturbances. The primary basis for the detection of stress conditions in a crop of other plan community by aerial remote sensors often, however, is not a change in the reflectance characteristics of individual leaves, but a reduction in the total leaf area exposed to the sensors. This reduction can result from a direct loss of leaves, a change in their orientation, or an overall suppression of plant growth. In such cases the total infrared reflectance tends to be decreased relatively more than the visible reflectance because of a reduction in the infrared enhancement due to fewer multiple leaf layers and because of an increase in background exposure.

Krumpe, P. F., H. R. Deselm, and C. C. Anderson. 1971. An Ecological Analysis of Forest Landscape Parameters by Multiband Remote Sensing. In: Proceedings of the Seventh Symposium on the Environment. Ann Arbor, Michigan. p. 715-130.

This study, part of multidisciplinary research under contract with the U.S. Department of Defense through Project THEMIS, tests remote sensor utilization and application in environmental studies. The purpose is to provide a means for predicting distributional and statistical parameters of vegetation in areas devoid of ground control. Ground truth studies used one-fifth acre targeted plot areas and point samples in which Southern Appalachian landscape attributes were quantitatively measured, relatively scaled or qualitatively classed. These included forest tree crown size, stand canopy closure, tree density and size, phenology, and other characteristics by species. Autumn and winter-flow 70 mm imagery obtained in different spectral bands at large and small photographic scales, were examined to assess the limits of this method in ground truth verification. Differing vegetation types characterized by nearly two dozen canopy size Deciduous Forest tree species, necessitated preparation of a dichotomous key to aid in species identification and the separation of community types. The key was based on stereoscopic examination of a 2000 tree sample, among which 33 crown foliage characteristics were documented and many designated Munsell color classes differentiated. Comparative studies between ground truth and film acquired data yielded predictive regression equations expressing their interaction. The validity of visual vegetation type mapping was tested by comparison with comprehensive ground control data. Preliminary use of the Tech/Ops Scandig Model 25 microdensitometer indicated the potential reliability of extending visual-manual species recognition techniques to semi-automated inventorying and mapping of Southern Appalachian natural area forest resources.

Lewis, Anthony J., and H. C. MacDonald. 1973. Radar Geomorphology of Coast and Wetland Environments. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Lake Buena Vista, Florida. p. 992-1003.

Side Looking Airborne Radar (SLAR) imaging systems are of special interest to the coastal and wetland geomorphologist. Continuous strip presentation of the land-water interface of at least 16 kilometers wide and hundreds of miles long is advantageous for the study of the relatively narrow coastal zone. In addition, the near all-weather, 24-h imaging capability is a particular asset in coastal and wetland environs commonly obscured by cloud cover. A variety of coastal environments have been imaged with commercial radar mapping systems during the past 10 yr. Some of these coastal areas include the Arctic Coast of Alaska, the Gulf Coast of Louisiana and Texas, the California and Oregon Coasts, Chesapeake Bay, and the Atlantic and Pacific Coasts of Central and South America. The wetland environment of the Atchafalaya Basin and the coastal swamp and marsh region in Louisiana have also been imaged. This study summarized the past work in radar coastal morphology by the authors and their co-workers but primarily focuses on recently complete research in the wetland environment of Louisiana and the coastal environment of Oregon.

Mairs, Robert L., and Denis K. Clark. 1973. Remote Sensing of Estuarine Circulation Dynamics. 39:929-938.

Multispectral and color aerial photography and infrared imagery of naturally occurring water color boundaries and/or dye tracer implants have been used successfully in the study of temporal coastal and estuarine circulation dynamics. Sequential photography and high-contrast enhancements of color imagery of fronts such as foam lines, current shears, etc., along with point and line sources of fluorescent dye are used to calculate and plot displacements and velocity vectors of water masses along the North Carolina coast and in the Patuxent River estuary, Maryland. Techniques have been developed for incorporation of remotely sensed data which are collected on a temporal scale ranging from minutes to hours, with extensive surface truth measurements to describe further the complex nature of estuarine flow.

Malhotra, R. C., and M. C. Rader. 1975. Locating Remotely Sensed Data on the Ground. In: Remote Sensing Energy Related Studies, T. Nejat Veziroglu, ed. Hemisphere Publishing Co. Seattle, Washington. p. 432-436.

This paper briefly discusses techniques for identifying the precise ground location represented by a specific set of remotely sensed data. Automated mathematical procedures using navigation (ephemeris) data and/or ground control points to identify the ground location of remotely sensed data sets by parametric modeling, "speculative" polynominal adjustment, and a method combining modeling and polynomial adjustment are described. Data from the NASA Skylab and the Earth Resources Technology Satellite (ERTS-1) projects are used in the examples given, but the basic methods apply to remotely sensed data collected from any aircraft or Earth-orbital satellite.

Markham, B. L., W. R. Philipson, and A. E. Russell. 1977. Airphoto assessment of changes in aquatic vegetation. In: Proceedings of the 43rd Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 504-516.

Large scale, multi-year, color and color infrared aerial photographs were used to evaluate changes in aquatic vegetation that have accompanied a reduction in phosphorus inputs to a phosphorus-limited, eutrophic lake in New York State. The study showed that the distribution of emergent, floating and submersed vegetation could be determined with little or no concurrent ground data; that various emergent and floating types could be separated and, with limited field checks, identified; and that different submersed types are generally not separable. Major vegetation types are characterized by spectral and non-spectral features, and a classification is developed for compiling time-sequential vegetation maps.

Marshall, J. R., and M. P. Meyer. 1978. Field Evaluation of Small-Scale Forest Resource Aerial Photography. Photo. Eng. 44(1):37-42.

Economic considerations prevent most forest land managers from obtaining conventional black-and-white medium-scale (circa 1:15,000-1:20,000) forest aerial photography at adequate intervals. Were smaller-scale photos comparably useful, the savings in procurement and interpretation costs could be used for more frequent overflights. Forested portions of Minnesota were flown with black-and-white infrared at scales of 1:15,840; 1:24,000; and 1:31,680 and with color infrared at scales of 1:1,680 and 1:80,000. Trained cooperators who analyzed the photographs under field-use conditions with high quality viewing equipment considered black-and-white forest photography at a scale of 1:24,000 marginally acceptable at best, and judged scales smaller than 1:24,000 unacceptable for the resource management applications involved. Overall, good quality summer black-and-white infrared 1:51,840 scale photography was preferred, but many user-cooperators were enthused about the potential of small-scale coverage as a supplement to, not a replacement for, conventional medium-scale photography. Color infrared transparencies provided more information than black-and-white prints of equivalent scale, but were considered overly cumbersone for day-to-day use under existing field office conditions.

McDowell, David Q. 1973. Determination of Spectral Reflectance Using Aerial Photography. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Lake Buena Vista, Florida. p. 408-423.

Many groups involved in remote sensing are concerned with the spectral reflectance of specific terrain elements. In some applications the spectral differences detectable visually with color film are adequate; for others a more detailed knowledge of the spectral reflectance curve is required. A technique has been proposed, using characteristic vector analysis, whereby a relationship can be developed between the spectral reflectance of a limited class of objects and the densities that these objects produce on a color film. This report describes a field test program conducted to evaluate the feasibility of this technique using low-altitude aerial photography of agricultural crops typical of upstate New York and *in situ* measurements of spectral reflectance. Reflectance curves were predicted over the 400- to 690-nm region with an average standard error of 0.0061 for samples of five different field crops that comprised the class of objects studied. Reflectance curves for two additional agricultural crops outside the basic group studied were also predicted with somewhat larger standard error.

McLaurin, John D. 1975. Information System for Aerial Photographers.
In: Proceedings of the 41st Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 154-161.

The National Cartographic Information Center has designed a summary record information system for aerial photographs. The system data base contains information on the geogrpahic extent of coverage and general characteristics of aerial photographs; first emphasis is on coverage at scales of 1:40,000 and smaller. In addition to information on current holdings the data base also contains information on planned photo acquisition. Participating agencies will regularly provide NCIC with the information in digital form for direct input to the data base. Each summary record includes the agency name, date of coverage, photo scale, film type, extent of coverage to the nearest 7.5-min quadrangel or by state and county, agency project code, and status (planned, in progress, or complete). One can search the data base using any of these parameters and obtain a computer-generated graphic indicating the extent of available coverage. Work is underway to expand the interactive capabilities of the system to provide different types of output. For the first time aerial photography users can readily keep informed on photo holdings and acquisition plans. The system's value depends directly on the agencies providing the essential input data. Thus NCIC is continually negotiating with organizations that collect aerial photographs, with the aim of providing complete information.

Mollay, Martin W., and V. V. Salomonson. 1973. Remote sensing and water resources U. S. space program. In: Remote Sensing and Water Resources Management Proceedings. No. 17. p. 6-38.

Since the launch of TIROS I in 1960, the utility of remote sensing from orbit for monitoring the earth's weather has been conclusively demonstrated. The past decade has also seen progress in applying remote sensing to the observation of terrestrial features. As in meteorology, networks of ground instrumentation are essential; their data may be relayed by satellite for calibration of orbital measurements. Variations in snow and ice cover, surface water, river and lake turbidity, and other hydrological features are now being accurately observed from orbital altitudes by the Earth Resources Technology Satellite (ERTS-1), NOAA-2, and

Nimbus 5. Satellite visible, infrared and microwave measurements will be continued over the next few years--with improved spatial and spectral accuracy--by Skylab, ERTS-B and Nimbus F. Delineations of soil and snow moisture variations, thermal patterns in lakes and estuaries, and regions of heavy precipitation are among the results anticipated. Operational earth resources survey programs are expected to evolve within the user agencies of the United States Government. Route repetitive, quantitative observations over watersheds as large as the Mississippi River are ultimately anticipated. These developments will provide input to regional and global numerical models that better predict, define, and manage the components of the hydrological cycle.

Molland, D. 1975. An Integration of Different Aerial Remote Sensors and Map Data in Making Engineering and Resource Studies. In: Proceedings of the Third Canadian Symposium of Remote Sensing. Edmonton, Alberta. p. 413-419.

Over 1,800 aerial remote sensing studies of environmental and resource projects have been reviewed. All studies, covering the period 1955 to 1975, involved the stereoscopic interpretation of panchromatic airphotos, mostly at the scale range 1:80,000 to 1:10,000. Airphoto mosaics scaled approximately 1:125,000 and contact prints scaled approximately 1:63,360 were used on all major hydroelectric and transportation route studies. Interpretations of several kinds of available maps and aerial and ground reconnaissance were carried out on the larger projects. Since 1972 Landsat-1 imagery has been used selectively on large corridor-type projects. Part of the review entailed identification of projects where the interpretation of Landsat-1 imagery either was or would have been signficantly helpful, marginally helpful, of questionable assistance, and of no assistance. The number and type of more common remote sensing studies carried out over 20 yr are listed. The types and scales of remote sensors and their integration with map and field work for a typical northern route corridor study are described. In addition, ways of increasing remote sensing expertise, especially for beginners, are briefly discussed.

Murtha, P. A. 1978. Symposium on Remote Sensing for Vegetation Damage Assessment. Phot. Eng. and Rem. Sens. 44:1139-1145.

A Symposium on Remote Sensing for Vegetation Damage Assessment was held in Seattle, Washington, U.S.A., on February 14, 15, and 16, 1978. Four invited and 27 presented papers were delivered during the Symposium. The papers dealt with (i) the theory of vegetation damage detection and assessment, (ii) the technologies involved, (iii) case studies, and (iv) economics and current applications. Resolutions were called for and submitted during the Symposium. The resolutions reflected the moods, present needs, and future concerns of the scientist and managers at the meeting. The resolutions asked for (i) ASP and ISP-Comm. VII support and encouragement of research into vegetative dysfunction relative to remote sensing; (ii) an international study on "previsual" or extravisual damage detection; (iii) more precise definition of "damage" and damage classes; (iv) coding of forest damage types in chronic vegetation damage situations; (v) quality control through use of defined confidence levels and statements of errors of estimates; and (vi) more effective technology information transfer at symposia, and at government or institutionally sponsored local area workshops.

Murtha, P. A. 1978. Remote sensing and vegetation damage: a theory for deflection and assessment. Photo. Eng. 44:1147-1158.

This paper discusses the philosophical and technical aspects of remote sensing for vegetation damage assessment. Answers are presented for these questions: (1) What constitutes remote sensing evidence of vegetation damage? (2) How is vegetation damage interpreted from remote sensed data? and (3) How can the damage be assessed? The answers to these questions are discussed in detail relevant to normal color and color-infrared aerial photography. Consideration is given to details of film reaction to variations in spectral reflectance patterns. Damages showing morphological or physiological changes are discussed relative to spectral reflectance changes and presented as a means to code damage types. An hypothesis for quantitatively monitoring forest damage is presented.

Nielson, U. 1972. Effects of Spectral Filtration and Atmospheric Conditions on Aerial Photography Obtained in 1970 and 1971. In: Proceedings, 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 411-416.

Photography obtained by the Airborne Sensing Unit provided material which illustrates many of the basic concepts of spectral reflectance, atmospheric attenuation and spectral filtration discussed in the paper. These concepts have to be understood and the presently very limited amount of information concerning spectral reflectance and effect of atmospheric factor has to be vastly increased if specifications for aerial photography are to be optimized.

Newhally, N. R., and R. E. Witmer. 1970. Remote Sensing for Land-Use Studies. Photo. Eng. 36:449-453.

The most common problems associated with interpreting land-use data are (1) incompatible and inconsistent use of terminology, and (2) developing useful and comparable classification systems. The interpretation and classification system proposed and tested here has two basic parts: land-use interpretation in as great detail as possible; and devising a classification system using the interpreted data which is specifically suited to the problem at hand. Sixteen photo interpretors participated in an experiment to test the validity and utility of the proposed system. They were divided into a control group which used any interpretation and classification system, and an experimental group which used the proposed system described in this report. Preliminary sampling analysis of these interpretations indicate that the members of the experimental group had the most detailed interpretations, produced more specific land-use data with less ambiguity, had fewer non-use classes, and employed more compatible classification systems.

Olson, C. E., and R. E. Good. 1961. Seasonal Changes in Light Reflectance from Forest Vegetation. Photo. Eng. 27:492-493.

During the 1960 growing season light reflectance from foliage of nine tree species was mesured weekly with a General Electric recording spectrophotometer for the wave-length range from 400 to 700 millimicrons. Sampling was begun in early May and continued through the fall color change terminating in November. Four replications were obtained for each species in each sampling period and all foliage sampled was taken from the south side of the upper quarter of the tree crown. All samples were picked between 10 a.m. and 2 p.m. local standard time, and reflectance measurements were completed within one hour of the time the foliage was picked. It was found that hardwood foliage reflected more light than pine foliage in almost all wave-lengths during all parts of the growing season. Differences in reflectance between hardwood and pine foliage decreased steadily from May to the beginning of the fall color change in hardwoods. Date of initiation of the fall color change varied with species but, in all hardwood species, the color change was characterized by increasing reflectance. When percent reflectance at 550 millimicrons was plotted over date, a seasonal pattern of changing reflectance seemed apparent in all hardwood species. Reflectance decreased during the early weeks of the growing season, remained nearly constant until mid- or late-summer, and then rose rapidly during the fall color change. A distinct, but short-lived, decrease in reflectance occurred in all hardwood species several weeks after the beginning of the fall color change. This pattern was also apparent when percent reflectance was plotted over data for 600 millimicrons.

Owen-Jones, E. S. 1977. Densitometer Methods of Processing Remote Sensing Data with Special Reference to Crop Type and Terrain Studies. In: Environmental Remote Sensing, E. C. Barrett and L. F. Curtis, eds. Crane and Russak, New York. p. 101-124.

The film portion affecting densitometric measurements are discussed in relation to general requirements for satisfactory results. Next, the principles of densitometry are reviewed, including a discussion of flat-bed, rotating-drum and flying-spot scanners. Applications of classification techniques to agricultural and natural terrain areas are also discussed. These include crop-type and terrain analysis from false colour photography obtained by the Skylark sounding rocket over Argentina and aircraft surveys in Australia. It is concluded that both supervised and unsupervised classification methods have their own particular merits. At the present time the state of the art does not preclude an element of subjective judgement.

Pakrekak, A. J., W. Sawka, and R. K. Schmidt. 1974. Analysis of Nesting Habitat of Canada Geese Using Remote Sensing Imagery. In: Second Canadian Symposium on Remote Sensing. Guelph, Ontario. p. 336-371.

The purpose of this study was to evaluate nesting habitat of Canada geese (Branta canadensis interior) in the Little Seal River Area of Manitoba using recent remote sensing imagery. Five different sets of imagery, all taken in August 1972, were carefully examined to determine which films best represented vegetation and landform features. Two types of color infrared photography proved to be most suitable and were used in delineating vegetation-landform (habitat) units on a study area map. These units were then compared with goose nesting data collected in spring, 1970. Canada geese nested in 6 of the 8 designated units but showed a marked preference for birch-willow and gravel ridge habitats. In general, results suggested that remote sensing imagery could be used to describe habitats in other, largely inaccessible goose breeding areas. Such an approach, if applied on a large enough scale, would provide new and relatively inexpensive ways of estimating annual production of Canada geese in the Eastern Prairie Population.

Polcyn, Fabian C., and D. R. Lysanga. 1973. Multispectral Sensing of Water Parameters. In: Remote Sensing and Water Resources Mngr. Proceedings No. 17. p. 394-403.

With the development of the multispectral scanner, improved techniques for mapping temperature gradients, turbidity, water color, and alga concentrations over large areas have been demonstrated. Where lake water transparency is sufficiently clear to detect light reflections from the lake floor a remote calculation of water depth is possible. Depth to 20 ft has been measured in the nearshore zone of Lake Michigan and near the Little Bahama Bank. Maps showing relative chlorophyll concentrations have been made for a portion of the shoreline areas near Port Sheldon, Michigan. Examples will be shown for the mapping of the terminal bar in Lake Michigan, river discharges, and the nearshore environment. Spectral characteristics related to chlorophyll concentrations were investigated for test samples across the thermal bar taken during the spring formation of the bar.

Rohde, W. G., and G. E. Olson, Jr. 1972. Multispectral Sensing of Forest Tree Species. Photo. Eng. 38:1209-1215.

Computer recognition of forest tree species at the NASA-Ann Arbor Forestry Test Site has been accomplished using data collected in six spectral regions between 0.4 and 1.0 micrometers. The six wavelength bands used were selected on the basis of laboratory reflectance data previously collected by the authors. Data obtained with The Unversity of Michigan C-47 aircraft and processed with the University of Michigan Spectral Analysis and Recognition Computer (SPARC), provided successful separation of coniferous and broad-leaved trees. Specific recognition and separation of sugar maple, black walnut, black locust, red oak, and white oak were also successful. Discrimination among conifers was not so successful as for broad-leaved species, but spruce were consistently separated from pine.

Sayn-Wittgenstein, L., and Z. Kalensky. 1974. Interpretation of Forest Patterns on Computer Compatible Tapes. In: Proceedings of the 2nd Canadian Symposium on Remote Sensing. Guelph, Ontario. Vol. 1:267-276.

The identification of spatial patterns should receive more emphasis in the interpretation of ERTS imagery. Spatial patterns can be recognized by involving such concepts and techniques as serial correlation, central tendency, periodicity and spectral analysis. The best results are obtained by using computer compatible tapes, rather than photographic images.

Scarpace, F. L. 1978a. Densitometry on Multi-Emulsion Imagery. Photo. Eng. 44(10):1279-1292.

Basic concepts of color densitometry and film calibration procedures are reviewed with special emphasis on the specific application to the remote sensing investigator. The differences between spectral, broad band, specular, diffuse, integral, and analytical densities are discussed and the instrumentation necessary for each type of measurement is described. An explanation of equivalent neutral density and methods of determining this type of density are presented. Methodologies of using analytical densities for the remote sensing community are detailed. The use of analytical densities in the construction of characteristic curves is discussed. Also included are comments made on reasons for using analytical densities in the analysis of film imagery and on proper application of the exposure values derived from the characteristic curves.

Scarpace, F. L., and G. L. Friederichs. 1978b. A Method of Determining Spectral Analytical Dye Densities. Photo. Eng. 44(10):1293-1301.

A straightforward method for the user of color imagery to determine the spectral analytical density of dyes present in the processed imagery is presented. The method involves exposing a large number of different color patches on the film which span the gamut of the film's imaging capabilities. From integral spectral density measurements at 16 to 19 different wavelengths, the unit spectral dye curves for each of the three dyes present were determined in two different types of color films. A discussion of the use of these spectral dye densities to determine the transformation between integral density measurements and analytical density is presented.

Scarpace, F. L. 1977. Densitometry on Color and Color IR Imagery. In: Proceedings of the 43rd Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D. C. p. 301-318.

Basic concepts of color densitometry and film calibration procedures are reviewed with special emphasis on the specific application to the Remote Sensing investigator. The differences between, and the instrumentation to measure the spectral, broad band, specular, diffuse, integral and analytical densities are discussed. An explanation of equivalent neutral density and methods of determining this type of density are presented. Methodologies of using analytical densities for the Remote Sensing community are detailed. The use of analytical densities in the construction of characteristic curves are discussed. Comments are made on reasons for the use of analytical densities in the analysis of film imagery and on proper application of the exposure values derived from the characteristic curves.

Scarpace, F. L., and P. R. Wolf. 1972. Convenient Atmospheric Refraction Equations. University of Wisconsin-Madison Remote Sensing Program. Madison, Wisconsin. 21 p.

Methods have been formulated for computing atmospheric refraction corrections to be applied to measured plate coordinates. The corrections may be calculated based upon any combination of flying height, ground elevation, atmospheric pressure, atmospheric temperature, and measured plate coordinates. The mathematical derivation of the equations is simple and the parameters used in the equations are readily measured. A theoretically exact method is presented firs˜, followed by other methods which are approximate and simplify the calculations. Tests have shown that the approximations consistently yield results that agree with the theoretically exact values to within one micrometer.

Scherz, James P. 1974. Errors in Photogrammetry. Photo. Eng. 40:493-500.

To teach and work effectively with photogrammetry, one should have a basic understanding of the sources and relative magnitude of errors inherent in aerial photographs. Exact calculus approaches are often so complicated that they cause one to want to forget about errors entirely and pretend they do not exist. The approach described herein equates all source error effects to a percentage, and as long as the mathematical manipulations are multiplication and division, the same percentages can be applied to the final answer to ascertain its probable error. The method described provides estimates of errors identical to those obtained using calculus, but the described method is much easier. The method provides students and users with a ready and quick method both for analyzing errors and for obtaining a feeling for the relative magnitudes of errors in photogrammetry work.

Scherz, J. P., and S. S. Ramchandra. 1973. A Practical Indexing and Retrieval System for Remote Sensing Data. In: Preceedings of the Am. Soc. of Photogrammetry Symposium on Management and Utilization of Remotely Sensed Data. Sioux Falls, South Dakota. p. 528-538.

Remote sensing imagery and support data is very valuable for any school or agency involved with mapping and environmental monitoring. However, this remote sensing data is all but useless unless it can be found and retrieved when needed. An interdisciplinary remote sensing library in which remote sensing data is index, catalogued, and filed by methods not entirely foreign to library methods used for books. The method of access in this program is a card catalogue system which contains the necessary pertinent data and a cross reference procedure which allows access to the data by users from various fields of interest. The system has proven very practical and usable, and can be adapted by any agency with a minimum of special personnel, training, and cost.

Schulte, O. W. 1951. The Use of Panchromatic, Infrared and Color Aerial Photography in the Study of Plant Distribution. Photo. Eng. 17:688-714.

(1) It is dangerous to generalize from one region to another in the selection of films. (2) Of the three films--panchromatic, infrared, and color--used in recognizing plant species of southeastern Canada, infrared is most preferable, and panchromatic and color about equal. (3) The infrared caused some confusion in distinguishing among dark conifers, water, cloud shadows, rock outcrops, and certain soils that print black. Ground details are obscured in shadow areas. There is poor distinction between all low herbaccous plants and dry or wet meadows and brushland. It is poor when the density count of a stand is desired. However, these disadvantages are outweighed by the superior results of infrared in delineating forest types, especially conifers and hardwoods, and by its ability to penetrate haze.

When such factors as size, location, association, tone, and texture are known, even the conifers and hardwoods can be broken down into smaller groups, or even species, more readily than on panchromatic. (4) Color photography is the least used because of cost. It is preferable for special problems, such as disease-control in summer, because it renders the leaves which have turned brown or yellow very evident. Any other disturbance of vegetation and consequent browning is rendered more visible on color photography. For a limited area it is better than panchromatic or infrared film for distinguishing hardwoods by color contrast in spring and autumn. During the summer, it is inferior to infrared for species identification. (5) Panchromatic is generally poorer in the east because of its failure to make the major distinction between conifers and hardwoods in the summer condition. Regardless of filters, the tones are often unreliable, and the textures not sufficiently differentiated to rate it over infrared. Panchromatic gives better detail for low shrubby areas, grasses, rocks, soils, roads, paths, houses, etc. The density of a forest can be estimated better on panchromatic. In the tundra of the North and the grasslands of the Plains where the vegetation is all shrubby (more or less), panchromatic is better than infrared since it produces more tonal differences and detail. (6) The film-filter-scale combination is a local problem and is dependent on the nature of the vegetation and the specific objectives desired. (7) In regard to keys, it is almost necessary to make one for each forest condition, and modified more or less for each flight. (8) The nearest approach to a practical key for recognizing species is a complete file for every recognizable species with stereoscopic ground and aerial photographs for all possible conditions. (9) The techniques of using hetero-stereoscopic pairs affords no real advantage over any single type. However, when all three types of film are available for a given area, then what is lacking on one film, can possibly be obtained on the other.

Slater, P. N. 1975. Basic Differences in the Quality of Analog and Digital Imagery from Photographic and Solid-State Array Remote Sensing Systems. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 139-153.

An analytical study has been made to compare the imagery from a solid-state array camera and a photographic film camera operating under the same conditions. The two cameras were chosen to be of the same size and to yield digital imagery of the same effective instantaneous field of view (EIFOV). The comparison covered both digital imagery, in which the film was scanned by a microdensitometer, and analog imagery, in which the output from the array was recorded on film. The digital imagery was evaluated with regard to signal-to-noise ratio (SNR) and minimum detectable ground reflectance difference ($\Delta\rho$); the analog imagery was evaluated with regard to visual resolution limit. The effects on the imagery of various atmospheric conditions and of different ground scene contrast ratios were also investigated. The most interesting result of the study is that the digital imagery from the solid-state array camera has a higher SNR than that from the film camera-microdensitometer system. Thus the array camera imagery is preferred for automated scene classification purposes. On the other hand, the visual resolution limit is at a higher spatial frequency for the imagery from the film camera than that from the array camera-film recorded system.

Thus the film camera is preferred for cartographic and mensuration applications.

Souto-Maior, Joel. 1973. Applications of Thermal Remote Sensing to Detailed Ground Water Studies. In: Remote Sensing and Water Resources Mngt. Proc. No. 17. p. 238-298.

Three possible applications of thermal (8-14 microns) remote sensing to detailed hydrogeologic studies are discussed in this paper: 1) the direct detection of seeps and springs, 2) the indirect evaluation of shallow ground water flow through its thermal effects on the land surface, and 3) the indirect location of small volumes of ground water inflow into surface water bodies. An investigation carried out with this purpose in an area containing a complex shallow ground water flow system indicates that the interpretation of the thermal imageries is complicated by many factors, among which the most important are: 1) altitude, angle of view, and thermal-spatial resolution of the sensor; 2) vegetation type, density, and vigor; 3) topography; 4) climatological and micrometeorological effects; 5) variation in soil type and soil moisture; 6) variation in volume and temperature of ground water inflow; 7) the hydraulic characteristics of the receiving water body, and 8) the presence of decaying organic material. Despite these limitations, the thermal remote sensing method can provide an array of hydrogeologic data not easily obtained by ground-based techniques. (KEY TERMS: thermal remote sensors; ground water to surface water temperature relationships; soil temperatures; landfills; ground water flow systems.)

Specht, M. R., P. Weedler, and N. L. Fritz. 1973. New Color Film for Water-Penetration Photography. Photo. Eng. 39:359-369.

The need for a film which will provide maximum information about underwater detail and water characteristics from photographs made from the air has led to the design of a special film for this purpose. A study of the transmittance characteristics of water shows that a film with two layers having peak sensitivities at about 480 and 550 nm will provide maximum penetration of water with various amounts of organic matter present. It will also allow some estimate of the amount of such material. Maximum detectability in the processed film is accomplished by providing that the dyes formed in the two layers are the complementary colors magenta and green, and that the contrast of the film be high. Aerial photographs made with an experimental film designed with the above characteristics show its superiority over regular color film for delineating underwater detail, and the distinct superiority of both over a film made by omitting the blue-sensitive layer from a regular color film.

Steiner, Dieter, et al. 1974. Digital Processing of Image Data for Automatic Terrain Recognition. In: Proceedings of the 2nd Canadian Symposium on Remote Sensing. Guelph, Ontario. p. 59-75.

This paper reports on selected aspects of more recent work carried out within a project dealing with the establishment of a digital image data processing capability. The objective is the development of techniques for the automatic or semi-automatic extraction of data on ground features and parameters. The topics covered include image data accessing, noise removal, geometrical image registration, the matching of map to image data, multispectral pattern recognition, spatial analysis and shadow analysis for the purpose of deriving building parameters in urban areas.

Steiner, Dieter. 1974. Digital Geometric Picture Correction Using a Piecewise Zero-Order Transformation. Remote Sensing of Environment 3:261-283.

This paper describes a procedure for the digital geometric registration of digitized air photographic data. Match points are located visually and used to formulate a global linear conformal transformation for each slave picture. Each transformation then serves to segment the corresponding image into regions such that, for the implementation of the correction, all pixels within a region can be shifted by the same number of rows and columns. In other words, the correction is achieved by a series of local translations (zero-order transformations). Remaining problems are then the filling of holes in the output pictures and the finding of a common submatrix. The image registration which results, provides a preprocessing operation needed to combine data from multitemporal and multispectral photography.

Steiner, Dieter. 1972. Multispectral-Multitemporal Photography and Automatic Terrain Recognition. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 601-609.

During the past few years progress has been made in the automatic recognition of terrain features on the basis of multispectral data gathering and pattern recognition methods. Particularly notable is research performed at the University of Michigan and at Purdue University (see, for example, Marshall and Kriegler 1971, and Laboratory for Agricultural Remote Sensing 1970) with sophisticated hard- and software, involving multispectral scanners and digital and/or analogue computer processing. The author of this paper, more interested in methodological aspects than in an operational system, started working in this area some years ago in Switzerland when at the Department of Geography, University of Zurich. These initial investigations were based on simple manual desitometric spot measurements on conventional aerial photography and their subsequent classification on a digital computer (Steiner et al. 1969). Since then, work has been coutinued at the University of Waterloo with somewhat more sophisticated techniques. The purpose of this paper is to report on progress made and future plans within a project started two years ago. The different phases of the program are summarized in Table 1.

Strong, Alan E. 1974. Remote Sensing of Algal Blooms by Aircraft and Satellite in Lake Erie and Utah Lake. Remote Sensing of Environment 3:99-107.

During late summer, when the surface waters of Lake Erie reach their maximum temperature, an algal bloom is likely to develop. Such phenomena, which characterize eutrophic conditions, have been noticed on other shallow lakes using the Earth Resources Technology Satellite (ERTS-1). The concentration of the algae into long streamers provides additional information on surface circulations. To augment the ERTS Multispectral Scanner Subsystem (MSS) data of Lake Erie an aircraft was used to obtain correlative thermal-IR and additional multiband photographs. The algal bloom is highly absorptive in the visible wavelengths but reverses contrast with the surrounding water in the near-IR bands. The absorption of shortwave energy heats the dark brown algal mass, providing a hot surface target for the thermal-IR scanner. A large bloom of Aphanizomenon flos-aquae observed in Utah Lake together with recent bloom history in Lake Erie is used to verify the Great Lakes bloom.

Tarnocai, C. 1972. The Use of Remote Sensing Techniques to Study Peatland and Vegetation Types, Organic Soils and Permafrost in the Boreal Region of Manitoba. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 323-335.

Multispectral imagery obtained in northern Manitoba was analyzed to determine the usefulness of remote sensing techniques in studying peatlands and permafrost. Dependable differences were found in the multispectral response patterns obtained from thermal infrared, near infrared color, color, panchromatic black and white and near infrared black and white photographs of the various peatland types. These differences made possible the separation and mapping of the peat landforms, vegetation, organic soils and permafrost. The cyclic nature of permafrost was also monitored using remote sensing data obtained in 1946, 1968, and 1971 and it was found that the area of permafrost decreased at a rate of 1 percent per year over the 25-year period studied.

Taylor, M. M. 1972. Perceptual Principles Related to Remote Sensing. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario.p. 497-503.

Remote sensing systems may be regarded as extensions of man's natural senses. As such, they should be governed by the same principles that govern natural perception. Perception is described as a means whereby information useful for action is separated from the enormous mass of useless information, and encoded in a way suited to rapid evaluation of potential behavior. This functional viewpoint leads to the idea that the "attention" of a "central processor" must be devoted at any one time to a small region of the environment and that a behaving organism should be provided with a large number of feature detectors which continually monitor the environment for items that deserve the attention of the central processor and send "alarms" when such features are detected. Attention should continually shift except when called by these alarms. The vigilance decrement is perhaps due to an inappropriate requirement that attention be deployed on a single display for continuous periods of time, and might be averted by transforming the display in such a way that targets appear in a manner to which natural "alarm" detectors are suited. Similarly, the provision of hardware feature detectors should be a major part of remote sensing used in searches for known target types.

Thie, Jean. 1972. Application of Remote Sensing Techniques for Description and Mapping Forest Ecosystems. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 149-169.

Remote sensing provides environmental studies with a true third dimension (accurate area distribution of parameters) and adds a fourth dimension, time. Careful interpretation of remote sensing imagery for individual elements of a forest ecosystem, like relief, drainage, vegetation, living organisms and time, supplies new and better information to describe and map ecosystems and to understand the interaction of its elements. Existing and potential applications of remote sensing techniques to analyse and describe these elements are discussed and examples given in three case studies.

Thiessen, H. W. 1972. A Proposed Organization for the Efficient Interpretation of Remote Sensing Data. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 719-722.

One season's experience of remote sensing service with the Remote Sensing Center in Alberta is described. This experience included several sources of photography in a variety of locations throughout the auspices of the interdepartmental Conservation and Utilization Committee. In addition, several departments of the federal government, and the University of Alberta, have participated in remote sensing photography within Alberta during the same period. Prior to this time, the researcher had other experiences with private contractors utilizing remote sensing in several interdisciplinary studies. Based on these experiences, Thiessen is convinced that the existing organization and use of remote sensing is not meeting the challenge of the need for this capability, nor is it anticipating the full potential of the technology. The development of an organization involving interdisciplinary analysis comprised by a variety of disciplines and supported by several levels of government and research insititutions is propsoed in order to realize the full potential of this science with the greatest efficiency to our taxpayers.

Ulaky, Fawwaz T., and R. K. Moore. 1973. Radar Spectral Measurements of Vegetation. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Lake Buena Vista, Florida. p. 322-334.

During the 1972 growing season 4-8 GHz radar backscatter spectral data was gathered at look angles between 0° and 70° for all four possible polarization linear combinations. The data covers four crop types (corn, milo, alfalfa, and soybeans) and a wide range of soil moisture content. To insure statistical representation of the results, measurements were conducted over 128 fields corresponding to a total of about 40,000 data points. This paper investigates the use of spectral response signatures to separate different crop types and to separate healthy corn from blighted corn.

Underhill, M. A. 1972. Problems in Relating User Requirements to Quantitative Parameters of Imagery Quality. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 533-546.

The techniques involved in the methodology of remote sensing are numerous and are generally subject to reasonably precise analytical measurement. The user (interpreter) of imagery from remote sensing systems is also trained in a scientific field whether it be forestry, geology or civil engineering, for example, and is used to dealing with precise analytical measurements in his own discipline. Unfortunately the quantitative terms which define image quality do not easily or formally translate into "usefulness" in terms of the discipline of the user requesting the imagery. Hence we are faced with the problem of quantifing those attributes of imagery that make it useful to the interpreter. More simply, what physical attributes constitute a "good" picture? And is that degree of goodness the same for all users? This paper will examine briefly some possible approaches in the problem of relating quantitative measurements of image quality in the user's requirements in different disciplines.

Wacker, A. G., and D. A. Landgrebe. 1972. Minimum Distance Classification in Remote Sensing. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 577-599.

The utilization of minimum distance classification methods in remote sensing problems, such as crop species identification, is considered. Minimum distance classifiers belong to a family of classifiers referred to as sample classifiers. In such classifiers the items that are classified are groups of measurement vectors (e.g. all measurement vectors from an agricultural field), rather than individual vectors as in more conventional vector classifiers. Specifically in minimum distance classification a sample (i.e. group of vectors) is classified into the class whose known or estimated distribution of the sample to be classified. The measure of resemblance is a distance measure in the space of distribution functions. The literature concerning both minimum distance classification problems and distance measures is reviewed. Minimum distance classification problems are then categorized on the basis of the assumption made regarding the underlying class distribution. Experimental results are presented for several examples. The objective of these examples is to: (a) compare the sample classification accuracy (% samples correct) of a minimum distance classifier, with the vector classification accuracy (% vector correct) of a maximum likelihood classifier; (b) compare the sample classification accuracy of a parametric with a nonparametric minimum distance classifier. For (a), the minimum distance classifier performance is typically 5% to 10% better than the performance of the maximum likelihood classifier. For (b), the performance of the nonparametric classifier is only slightly better than the parametric version. The improvement is so slight that the additional complexity and slower speed make the nonparametric classifier unattractive in comparison with the parametric version. In fact disparity between training and test results suggest that training methods are of much greater importance than whether the implementation is parametric or nonparametric.

Watson, Robert D., W. R. Hemphill, and T. D. Hessin. 1973. Quantification of the Luminescence Intensity of Natural Materials. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on the Management and Utilization of Remotely Sensed Data. Sioux Falls, South Dakota. p. 364-376.

Rhodamine WT is an artificial, water-soluble, organic dye used as a tracer by hydrologists and oceanographers to monitor the dynamics of currents in rivers and estuaries. In 1969, rhodamine dye was detected in sea water in concentrations of less than 2 μg/liter (2 ppb) with the aid of a prototype Fraunhofer line discriminator, an optical-mechanical remote-sensing device, which has been used in the detection of solar-stimulated luminescence from aircraft. Continuing experiments with a laboratory fluorescence spectrometer indicates that luminescence of some samples of crude and refined petroleum exceeds the luminescence intensity of rhodamine dye in concentrations of 10,000 g/liter (10,000 ppb). It has also been determined that luminescence of some conifer needles and other plants is comparable to dye concentrations of 50 g/liter (50 ppb). Conifer needles collected from trees growing in high-copper-zinc soil west of Denver, Colorado, show markedly greater luminescence intensity than needles from conifers growing nearby in unmineralized areas. These luminescene intensities appear to be within the sensitivity limits of a Fraunhofer line discriminator.

Wilson, C. L., and R. H. Rogers. 1975. Multispectral Data Systems for Energy Related Problems. In: Remote Sensing Energy-Related Studies. T. Nejat Veziroqu, ed. Hemisphere Pub. Co. Seattle, Washington. p. 404-429.

A multispectral data system consists of data collection, data processing, data analysis and interpretation, and information dissemination (application) subsystems. The ERTS MSS and the data processing facility at Goddard Space Flight Center are examples of the first two subsystems respectively. The characteristics of airborne and satellite digital multispectral scanner data are described, together with the digital data processing and analysis techniques which have been developed to automatically analyze and interpret the data. Techniques for output product generation and information dissemination are illustrated using strip mine monitoring and environmental impact assessment for power plant siting and transmission line routine as examples. The problems associated with the development of semi-automated performance of the cited applications are discussed, as well as the current status of the development programs. Expected trends in the development of operational application subsystems are presented.

Worsfold, R. D. 1972. A Qualitative Study of Kodak Aerochrome Infrared Film, Type 2443, and the Effect Produced by Kodak Colour Compensating Filters, at High Altitudes. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Canada. p. 417-427.

AETE Uplands, Photo Development (now Canadian Forces Airborne Sensing Unit), on 18 August 1970 carried out film/filter tests using Aerochrome Infrared Film, Type 2443, at altitudes of 20,000 ft and 40,000 ft with Vinten 492 and Vinten 547 aerial reconnaissance cameras. The purpose of the test was to contribute film/filter samples to a catalogue of examples of forested land, land forms, geologic formations, agricultural land, and industrial land being compiled for mission planning. Utilizing the various film/filter combinations and evaluating each filter with respect to the film, selected positive transparencies, with seventy millimeter format and in stereotriplets, were collected and analyzed for use in the Canadian Forces Airborne Sensing Unit (CFASU). From the examples, a study was undertaken to determine which of the examples could be interpreted in two ways; common photo interpretation techniques and infrared information content. The results could be tabulated in relation to each other. The film/filter combinations are available at CFASU for the use of investigators in mission planning.

Yost, Edward, and S. Wenderoth. 1971. Multispectral Color for Agriculture and Forestry. Photo. Eng. 37:590:604.

The potential usefulness of multispectral color photography for the identification of crop and tree species has been demonstrated in a series of controlled experiments using broad-band camera filters which approximate the spectral sensitivity of color and color-infrared films. Independent adjustment of exposure in each camera band, control over the gamma and density of the photographic image, along with the ability to adjust the hue, brightness, and saturation in viewing, resulted in greater image chromatic separation than could be achieved using subtractive color reversal films. The capability to compensate for variations in the solar illuminant and atmospheric attenuation using additive color viewing of multispectral photographs was demonstrated.

Zsilinszky, V. G. 1972. Camera Mounts for 35 mm Mono and Multi-Spectral Photography. In: Proceedings of the 1st Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 441-450.

Supplementary aerial photography with miniature cameras is a commonly used tool in various resource survey activities of the Ontario Department of Lands and Forests. Developmental work, specific and routine applications require both conventional and unconventional treatments. Sometimes a single camera is capable of providing complete information, while at other times combination photography is prescribed. Consequently, mounts of various capacity have been engineered for single, two, three and four cameras. Each working model is described and illustrated, principles involved are discussed and it is suggested that the designs offered could apply to most miniature cameras and light aircraft with minor alterations or with no modifications at all.

## Additions to REMOTE SENSING--GENERAL INFORMATION

American Society of Photogrammetry. 1975. Manual of Remote Sensing. Falls Church, Virginia. 2144 p.

The Manual of Remote Sensing was written (1) to replace and update material contained in the Manual of Photographic Interpretation and (2) to provide information on the new techniques of Remote Sensing and their uses. Volume I includes extensive treatment of the electromagnetic theory behind Remote Sensing; interaction of electromagnetic radiation with solid, liquid and gaseous matter; and the instruments and their platforms used to obtain remote sensor data. The techniques of processing these data to allow the interpreter to obtain the maximum information from them is also included. Volume II treats the fundamentals of imagery interpretation, and illustrates in detail how Remote Sensing may be applied to a wide variety of scientific and natural resources fields.

Lillesand, T. M., and R. W. Kiefer. 1979. Remote Sensing and Image Interpretation. John Wiley and Sons. New York. 612 p.

This is a definitive remote sensing and image interpretation text. Its ten chapters cover concepts and foundations of remote sensing; elements of photographic systems; basics of airphoto interpretation; airphoto interpretation for terrain evaluation; photogrammetry; radiometric characteristics of aerial photographs; aerial thermography; multispectral scanning and spectral pattern recognition; microwave sensing; and remote sensing from space.

Swain, P. H., and S. M. David, eds. Remote Sensing: The Quantitative Approach. McGraw-Hill, New York, New York. 396 p.

This technical reference book covers radiation and instrumentation in remote sensing; fundamentals of pattern recognition in remote sensing; data-processing methods and systems; biological and physical considerations in applying computer-aided analysis techniques to remote sensor data; applying the quantitative approach, and useful information for multispectral image data: another look.

## REMOTE SENSING OF WETLANDS

The following references are concerned with identifying wetland vegetation, high water lines, and mapping wetlands using a variety of photographic and multispectral scanner platforms. The references deal with both coastal and freshwater wetland systems.

Anderson, Richard R., Virginia Carter, and John McGinness. 1973. Applications of ERTS Data to Coastal Wetland Ecology with Special Reference to Plant Community Mapping and Typing and Impact of Man. In: Proceedings of the Third Earth Resources Technology Satellite-1 Symposium, Vol. 1, Technical presentations, Section B.

Complete seasonal ERTS-1 coverage of Atlantic coastal wetlands from Delaware Bay to Georgia provides a basis for assessments of temporal data for wetland mapping, evaluation, and monitoring. Both MSS imagery and digital data have proved useful for gross wetland species delineation and determination of the upper wetland boundary. Tidal effects and (band to band or seasonal) spectral reflectance differences make it possible to type vegetatively coastal wetlands in salinity-related categories. Management areas, spoil disposal sites, drainage ditches, lagoon-type developments, and highway construction can be detected indicating a monitoring potential for the future. A northern test site (Maryland-Virginia) and a southern test site (Georgia-South Carolina), representing a range of coastal marshes from saline to fresh, were chosen for intensive study. Wetland maps were produced at various scales using both ERTS imagery--band 5 and 7--and digital data--bands 4, 5, and 7. A Bausch and Lomb Zoom Transfer Scope and various overlay techniques were used with either 9 1/2" black and white transparencies or enlarged black and white prints. Diazo color composites, color enhancement techniques, and multi-spectral manipulation were used to supplement this information. Data will be useful for coastal wetland inventories, updating acreage estimates, mapping boundaries, detecting seasonal changes, detecting and monitoring man's impact. Resolution limitations allow for mapping to a 1/125,000 scale. Results are being applied directly to a Dismal Swamp study with U.S. Geological Survey. There is potential application to on-going programs in Georgia and South Carolina and to the Coastal Zone Management Act and a National Wetlands law.

Anderson, Richard R., Virginia Carter, and John McGinness. 1973. Mapping Atlantic Coastal Marshlands, Maryland, Georgia, Using ERTS Imagery. In: Proccedings of the 39th Annual Meetng of the Am. Soc. of Photogrammetry. Vol. 1. p. 615-625.

Eastern coastal marshes are the most extensive and productive in the United States. A relatively low cost, moderately accurate method is needed to map these areas for management and protection. Ground based and low-altitude aircraft methods for mapping are time-consuming and quite expensive. The launch of NASA's Earth Resources Technology Satellite has provided an opportunity to test the feasibility of mapping wetlands using small scale imagery. The test sites selected were in Chesapeake Bay, Maryland and Ossabaw Island, Georgia. Results of the investigation indicate that the following may be ascertained from ERTS imagery, enlarged to 1:250,000; (1) upper wetland boundary; (2) drainage pattern in the wetland; (3) plant communities such as *ens, Juncus roemerianus*; (4) ditching activities associated with agriculture; (5) lagooning for water-side home development. Conclusions are that ERTS will be an excellent tool for many types of coastal wetland mapping.

Anderson, R. R., and F. J. Wobber. 1973. Wetlands Mapping in New Jersey. Photo. Eng. 39(4):353-358.

The New Jersey Wetlands Act of 1970 required that mapping and inventory of wetland along the marine coastal zone and tide-influenced estuaries of the State be properly managed. A prime requirement was that map products have validity which could withstand the challenge of litigation. Natural-color and color-infrared aerial photographs at a scale of 1:12,000 were obtained over two sites designated by the State. Final map products were prepared containing (a) the upper wetlands boundary; (b) the line of biological mean high water to establish state riparian lands; and (c) delineation of major plant species associations of five acres or larger in size. The state-wide wetlands mapping effort will be one of the largest operational remote sensing projects ever conducted. The authors believe that the methods developed, ecological data collected, and products prepared will have far-reaching effects on future coastal zone programs.

Bartlett, D. S., V. Klemas, R. H. Rogers, and N. J. Shag. 1977. Variability of Wetland Reflectance and its Effect on Automatic Categorization of Satellite Imagery. In: Proceedings of the 43rd Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 70-80.

A technique for training automated analysis of satellite (LANDSAT) multispectal data based on *in situ* measurements of target reflectance was tested and applied in delineating cover typed in Delaware's tidal wetlands. This technique evaluated used *in situ* measurements of target radiance and an atmospheric correction procedure to derive reflectance signatures for land-cover categories in preference to the relative radiance signatures traditionally derived from training samples within the satellite data itself. Land cover categorization of data from the same overpass in four test wetland areas was carried out using a four-category classification system. The tests indicate that training data based on *in situ* reflectance measurements and atmospheric correction of LANDSAT data can produce comparable accuracy of categorization to that achieved using more conventional relative radiance training. The analysis of the four wetlands cover categories (Salt March Cordgrass, Salt Hay, Unvegetated, and Water Tidal Flat) produced overall classification accuracies of 85% by conventional relative radiance training and 81% by use of *in situ* measurements. Overall mapping accuracies were 76% and 72% respectively. Further refinement of the atmospheric correction and ground measurement procedures should produce better accuracies in a more operational mode. In addition, field measurements showed that variability in spectral reflectance was, as expected, symptomatic of significant physical characteristics of the test cover types such as time elapsed since tidal inundation of mud, plant height, and growth form. Significant correlations were found between single band reflectances and tidal inundation and plant morphologic characteristics. Optimazation of seasonal sampling procedures for detection of plant morphologic parameters is suggested.

Boissonneau, A. N., and J. K. Jeglum. 1975. A Regional Level of Wetlands Mapping for the Northern Clay Section of Ontario. In: The Third Canadian Symposium on Remote Sensing. Edmonton, Alberta. p. 349-357.

A study in the Hicks Township, 72 kilometers northwest of Timmins, in the Northern Clay Section of Ontario, was selected to test the feasibility of using remote sensing data to map the wetland types of a proposed wetlands classification framework. It was found that although broad patterns of wetlands types could be mapping using densitometric analyses of LANDSAT imagery, this section could be most efficiently classified using large-scale aerial photography. It was also found that large-scale photography could be used to identify the most detailed level of the proposed wetlands classification. In the regions to the north of the Northern Clay Section which are vast and almost exclusively wetlands, and for which LANDSAT imagery provides the best or the only remote sensing data, it is anticipated that densitometric analysis of LANDSAT imagery will be an efficient means of extrapolating ground truth data to the lands of these regions.

Bright, C. R., and H. R. Pywell. 1978. Data Base Development for the National Wetlands Inventory. In: Proceedings of the 44th Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 329-334.

Autometric, Inc. has developed a data base system for the storage and retrieval of digital geographic data. This information is stored on a geounit basis which may be queried through a FORTRAN program written to interrogate the data base. Reports on wetland area and types may be generated along with 7 1/2 and 15 minute quadrangle plots utilizing an on-line, high speed digital plotter. The data base structure is also supportive to aerotriangulation and digitizing stations for the generation of wetland information.

Brocon, W. W. 1978. Wetland Mapping in New Jersey and New York. Photo. Eng. 44(3):303-314.

The wetlands of New Jersey and New York were mapped recently using 1:12,000 scale color and/or color infrared aerial photographs. In support of tidal wetlands legislation, the Mean High Water (approximate position) and Upper Wetland Boundary lines were delineated using a biological entity--plant species. In New Jersey, dominant plant species were identified on each map (Anderson and Wobber 1973). In New York, a broader classification system was used based on plant species categories such as Coastal Fresh Marsh, High Marsh, etc. These projects represent two distinct approaches by which wetland surveys may be conducted. For successful implementation of projects of this type, it is critical that mapping conventions and procedures be developed at the onset of the program. These mapping criteria, howeer, may be modified as the program proceeds and the need arises. Also, a thorough understanding of aerial photographic interpretations of plant species signatures under varying conditions is essential.

Carter, Virginia. 1974. Remote Sensing Applications to the Dismal Swamp. Paper Presented at the Great Dismal Swamp. Symposium, Old Dominion University, Norfolk, Virginia. 34 p.

The recent Dismal Swamp Study (Public Law 92-478) is an example of the use of remotely sensed data in a multidisciplinary study to assess the multiple-use potential of a large inland wetland. Remotely sensed data available for the Dismal Swamp include aircraft photography, Earth Resources Technology Satellite (ERTS) data, and thematic extractions. These data were applied to (1) overall study area selection, (2) location of intensive study areas, (3) hydrologic studies, (4) vegetation mapping, and (5) field studies including identification of special interest areas. The large size of the Dismal Swamp and the inaccessibility of many interior parts makes remote sensing an important tool to meet the needs of the current study as well as future research and management.

Carter, V., A. Voss, D. Malone, and W. Godsey. 1976. Wetland Classification and Mapping in Western Tennesee. In: Proceedings of the Second Annual William T. Pecora Memorial Symposium. Sponsored by The American Society of Photogrammetry and the U.S. Geological Survey. p. 206-220.

The U.S. Geological Survey and the Tennessee Valley Authority are presently conducting a cooperative wetland mapping project in western Tennessee. Existing wetland classification systems were considered too general to supply needed management information, so a new system has been developed based primarily on vegetation, and frequency and duration of inundation. There are five forested wetland subclasses and seven non-forested wetland subclasses in the new system. High altitude color infrared photography was acquired by the National Aeronautics and Space Administration during several seasons. This photography supplied the information on hydrologic boundaries and vegetation that is needed for classification and mapping. Seasonal information was required to map the maximum number of categories. The methodology for separating and delineating classes was carefully documented. The state (water level) was determined for the time of overflights for sites where gage stations are in operation. Under the new classification system, wetlands at four sites were mapped at 1:24,000 scale as overlays on the existing Geological Survey 7.5-minute topographic map series. Adjacent land use was also mapped, but in less detail than wetlands. Overlays for separate dates were combined to make the final camera ready copy. A lithographed map of wetlands and land use was made for one of the five quadrangles covering the Reelfoot Lake site. The stage at time of photography was referenced to a stage-duration curve, placed on the map collar, to show that boundaries are representative of average water levels rather than extreme highs or lows.

Carter, Virginia, and Jane Schubert. 1974. Coastal Wetlands Analysis from ERTS MSS Digital Data and Field Spectral Measurements. In: Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. p. 1241-1260.

Classification, delineation and evaluation of coastal wetlands can be made on the basis of major vegetative associations. To produce wetland maps, two vegetation-analysis look-up tables were developed for use in the ERTS ANALYSIS System. These look-up tables are based on Earth Resources Technology Satellite (ERTS) digital values in Multispectral Scanner (MSS) bands 4, 5, and 7 and were developed using seasonal spectral reflectance measurements from field observations. Computer-generated maps at an approximate scale of 1:120,000 were produced for the primary test site, Chincoteague Marsh, Virginia. There is a high degree of accuracy in the identification of wetland features and plant associations. The classification was also tested on other Atlantic coast salt marshes and a brackish marsh in the Chesapeake Bay.

Carter, Virginia, and Richard R. Anderson. 1974. Multispectral Analysis for Wetland Studies. Paper Presented at the Winter Meeting of the Am. Soc. of Agri. Eng., St. Joseph, Michigan. 16 p.

Multispectral data have been used successfully for wetland studies. The applications discussed include the use of the Earth Resources Technology Satellite (ERTS) Multispectral Scanner (MSS), the SKYLAB S190A Multispectral Photographic Facility, and the Bendix 24-channel scanner. ERTS imagery and digital data have been used to classify wetlands, map coastal wetland features, and estimate primary productivity (Virginia and South Carolina). ERTS data have also been used to study the vegetation and hydrology of the Dismal Swamp (Virginia/North Carolina). SKYLAB data are being used to classify and map wetlands in the Chesapeak Bay area. Multispectral data from low-altitude aircraft are presently being used to determine species composition in fresh, brackish, and saline marshes in the Chesapeake Bay area.

Civco, D. L., W. L. Kennard, and M. W. Lefor. 1978. A Technique for Evaluating Inland Wetland Photointerpretation: the Cell Analytical Method (CAM). Photo. Eng. Vol. 44(8):1045-1052.

A procedure for objectively analyzing the inland wetland photointerpretation of several investigators is discussed. Comparisons are made between wetland photointerpretations, soils mappings, and ground truth. The technique, which permits mathematical treatments of cell-encoded wetland delineations, was developed to test inland wetland mapping methods. Results indicate that interpretation of false-color infrared (FCIR) aerial photographs produces more accurate wetland delineations than can be obtained from soils maps, especially at a mapping unit level useful in wetlands management. Desirable qualities of photointerpreters who are to perform wetland delineations are discussed as are the relative merits, in terms of wetlands characterization, of aerial photography from different seasons.

Cowardin, L. M., and V. I. Myers. 1971. Remote Sensing for Indentification and Classification of Wetland Vegetation. J. Wild. Manage. 38(2):308-314.

Multispectral photography and ground truth were obtained on an area 12 miles (19.3 km) east of Bemidji, Minnesota, to identify and map wetlands less than 2 acres (0.8 ha) in size, to map emergent vegetation in lakes, and to explore the feasibility of classifying vegetation from aerial photographs. Wetlands less than 2 acres in size were identified on photography taken in May 1971, and emergent vegetation was recorded on purposely overexposed infrared black and white photography from a flight in September 1971. Several vegetation types and species groups were recognizable with the aid of color, color infrared, and black and white infrared photography. Proper timing of flights, use of multispectral photography, and knowledge of the ecology of the area are considered essential for wetland mapping by remote sensing.

Egan, W. G., and M. E. Hair. 1969. Automated Delineation of Wetlands in Photographic Remote Sensing. In: Proceedings of the 7th International Symposium on Remote Sensing of the Environment. Ann Arbor, Michigan. Vol. 3. p. 2231-2252.

Precision automated photometric mapping of wetlands in Calvert County, Maryland has been achieved in an operational system as the result of a program including aerial color film (both true color and false color infrared) calibration and control. Although the system was operated over this area, it may be adapted to other areas. The recognition appears to be most accurately achieved by microdensitometric analysis of the true color transparency in a narrow band centered in the red (0.633 um), on 3000-ft altitude imagery. A computer generated map is obtained.

Enslin, W. R., and M. C. Sullivan. 1974. The Use of Color Infrared Photography for Wetlands Assessment. In: Remote Sensing of Earth Resources Conferences. The University of Tennessee Space Institute, Tullahoma, Tennessee. Vol. III. p. 697-720.

A study was undertaken of Pointe Mouille Marsh, located on Lake Erie, to assess shoreline erosion and to inventory and evaluate adjacent land as potential replacement for areas lost to erosion, and to provide better data sources for management decisions. The results of the study were (1) evaluation of low altitude oblique photography was useful in determining specifications of operational mission requirements; (2) Accurate base map revisions reflecting shoreline erosion were made using aerial photography and a Zoom Transfer Scope; (3) An aerial land cover inventory provided data necessary for selection of adjacent lands suitable for marshland development; (4) A detailed inventory of vegetative communities (mapped from CIR), was made for management decisions; and (5) A carefully selected and well laid-out transect was a key asset to photo interpretation and analysis of vegetation.

Fornes, Ann O., and Robert J. Reimold. 1973. The Estuarine Environment: Location of Mean High Water--Its Engineering, Economic and Ecological Potential. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Lake Buena Vista, Florida. p. 938-978.

The demarcation of mean high water is important in terms of utilization and protection of the coastal zone. The paper considers various methods by which mean high water was located in a salt marsh. The work was conducted at two study sites located on the Duplin Estuary, Sapelo Island, Georgia. Each site had a number of photo-identifiable targets established prior to the time the photographic mission was flown. Bench marks on a first order level were available nearby in order to tie in elevations of the marsh to a U.S.G.S. bench mark. Also, four recording tide gauges, monitored for over a year, permitted determination of local mean high water.

Ground control for each site was established by surveying elevations of the large white disks and obtaining distances between them. This information was used to rectify color infrared positive transparencies for use in the Kern PG-2 plotter. The elevation of the calculated mean high water was then photogrammetrically located.

Delineation of plant species using color infrared photographs represented the method of biologically locating mean high water. In this case, the vegetation was considered to be an accurate indicator of environmental conditions.

Finally, thermal imagery was considered, attempting to locate an isotherm coincident with mean high water. This was based on the premise that the most frequently flooded zones would be wetter, thus cooler, whereas drier areas, more often escaping flooding, would be warmer. Each method was then viewed in terms of the cost, accuracy, speed of delineation and overall validity.

Topographic mapping was found to be slow and inaccurate, despite the fact that it is the standard procedure used for upland surveys. Biological and thermal mapping techniques were faster techniques by which to delineate mean high water. Both were also more accurate, as such boundaries are easily recognizable. Variation in area covered was greatest, however, in the thermal imagery method. The biological method, therefore, was not only more accurate and faster to delineate than topographic techniques, but also afforded a high degree of reproducible results, not obtainable by the other two methods. With the present knowledge of remote sensing techniques, biological delineation appears to be the most effective method to locate mean high water.

Gallagher, J. L., D. E. Thompson, and R. J. Reimold. 1972. Remote Sensing and Salt Marsh Productivity. In: Proceedings of the Symposium on Coastal Mapping. Am. Soc. of Photogrammetry. Falls Church, Virginia. p. 18-31.

The feasibility of using photography or thermal imagery from fixed wing aircraft for assessing salt marsh productivity is being investigated. Kodak Aerochrome Infrared 2443 and Aerocolor negative 2445 films and a Bendix Thermal Mapper are being used. Remote sensing flights (from 1,250 to 20,000 ft) are made in conjunction with acquisition of ground truth data consisting of chlorophyll per unit area, the density of living and dead plants by number, and biomass for each species and each one-half meter height class.

A number of windows in the 2 to 13 micrometer wavelength range are being tested with the thermal mapper to ascertain which gives the best discrimination of spatial productivity patterns. Color enhancement of the imagery has proven useful in defining the extent of these areas and predicting tidal hydrography in the intertidal zone.

Color patterns in the color-infrared photography, due in part to differences in plant species, density, growth form and pigmentation, are being quantified by: (1) planimetry of hand-drawn visual interpretations of projected transparencies; (2) planimetry of visual interpretation using a Kern plotter; and (3) microdensitometry of each zone defined by a Joyce Loebl Microdensitometer coupled with a four color isodensitracer.

Photographs are used to predict productivity at untested locations within the study areas and ground truth is collected at these sites during subsequent sampling periods.

Gammon, P. T., and V. Carter. 1979. Vegetation Mapping with Seasonal Color Infrared Photographs. Photo. Eng. 45(1):87-97.

The Great Dismal Swamp of Virginia-North Carolina is a forested wetland which has been extensively altered by fire, timbering and ditching. Seasonal high and low-altitude color infrared photographs of the swamp have been used to identify and map specific swamp vegetative communities. These photographs provided the capability to distinguish among deciduous species, to evaluate understory, to separate broad-leaved evergreen and deciduous species, and to locate several special community types. Comparisons made of data from different seasons frequently helped to distinguish between other wise obscure classes. Vegetative cover classes for the Great Dismal Swamp were defined to provide maximum habitat information for management of the swamp by the U.S. Fish and Wildlife Service. These classes were based on dominant canopy designations and 243 specific vegetative communities were distinguished. Class combinations in the map units were ranked by relative dominance as observed on the color infrared photographs. Evaluation of class accuracy was accomplished by helicopter overflight using sample sites selected by two methods. A canopy or understory map unit was considered correct if at least one of the classes was identified in the field sample. Using this criterion, canopy accuracy was 93.8 percent and understory accuracy was 90.5 percent. A vegetation map was prepared at a scale of 1:100,000 using a U.S. Geological Survey 7.5 minute orthophotomosaic as the base map.

Garvin, Lester E., and Richard H. Wheeler. 1972. Coastal Wetlands Inventory in Maryland. In: Proceedings of the Symposium on Coastal Mapping. Am. Soc. of Photogrammetry. Washington, D.C. p. 18-31.

In 1970 the State of Maryland passed legislation to protect its coastal wetlands from further despoilation through uncontrolled dredging, ditching and filling. In October 1971, Raytheon/Autometric began working with the State Agency responsible for implementing the law, the Department of Natural Resources, to undertake a statewide inventory of coastal wetlands. The legislation and inventory methodology are described. The methodology of implementation is cost effective and represents a sound approach to the problem of protecting finite natural resources.

Guth, Jack E. 1974. Will the Real Mean High Water Line Please Stand Up. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Washington, D.C.p. 33-44.

The accurate location of the Mean High Water (MHW) line is of primary importance for determination of coastal property boundaries. A clear understanding of tidal characteristics is required to accomplish this. Some historical survey methods are no longer acceptable. A proposed system is identified by the initials TAG to represent its three basic elements: T for tide data, A for aerial photographic mapping, and G for ground surveys. There are areas where it is not practical to establish the MHW line by methods normally used. In such cases political determination may be the most reasonable solution; however, this alternative should be used with caution.

Hubbard, J. C. E., and B. H. Grimes. 1972. Coastal Vegetation Surveys. In: Environmental Remote Sensing: Applications and Achievements, Eric C. Barrett and Leonard F. Curtis, eds. Crane & Russak, New York. p. 129-141.

Aerial photography has proved to be a fruitful means of documenting and analyzing vegetation in coastal zones. This paper reports some of the recent successes achieved through the investigation of coastal patterns recorded in both the visible and non-visible portions of the electro-magnetic spectrum. Drawing examples from the coasts of southern Britain, France and Spain, it deals in turn with the vegetation of mudflats, salt-marshes, shingle beaches, sand-dunes, and cliffs. Few such habitats lend themselves to easy mapping on the ground, owing to such factors as inaccessibility, the tidal cycle, and the instability of certain surfaces.

Klemas, V., D. Bartlett, and F. Daiber. 1973. Mapping Delaware's Coastal Vegetation and Land Use from Aircraft and Satellites. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Lake Buena Vista, Florida. p. 926-937.

Coastal vegetation species appearing in ERTS-1 images taken of Delaware Bay have been correlated with ground truth vegetation maps and imagery obtained from RB-57 and U-2 overflights. Multispectral analysis of the high altitude RB-57 and U-2 photographs indicates that four major vegetation communities can be clearly discriminated from 60,000 ft altitude including (1) salt marsh cord grass (*Spartina alterniflora*) (2) salt marsh hay and spike grass (*Spartina patens* and *Distichlis spicata*), (3) reed grass (*Phragmites communis*), and (4) hight tide bush and sea myrtle (*Iva frutescens* and *Baccharis halimifolia*). In addition, human impact can be detected in the form of fresh water impoundments built to attract water fowl, dredge-fill operations and other alterations of the coastal environment. Overlay maps matching the USGS topographic map size of 1:24,000 have been prepared showing the four wetland vegetation communities, fresh water impoundments and alteration of the wetlands by mosquito control ditching and dredge-fill operations. Using these maps for basic ground truth, ERTS-1 images were examined by human interpreters and automated multispectral analyzers. Major plant communities of (1) *Spartina alterniflora*, (2) *Spartina patens* and *Distichlis spicata*, and (3) *Iva frutescens* and *Baccharis halimifolia* can be distinguished from each other and from surrounding uplands in ERT-1 scanner bands #6 and #7. *Phragmites* *communis*, which naturally occurs in small dispersed patches, can be identified only in the heavily disturbed marshes of northern Delaware where it has propagated over large areas. Fresh water impoundments built to attract water fowl, major dredge-fill construction and other vestiges of human land-use can also be identified in ERTS-1 scanner bands #5, #6, and #7. The potential for monitoring such activity from space appears considerable. The maps showing coastal vegetation species and land use, including changes in land use, are being further developed into relative value maps for the wetlands. It is this kind of information that public officials and planners need to assess socio-economic benefits of coastal development with full recognition of potential environmental impacts.

Klemas, V., F. Daiber, D. Bartlett, O. Crichton, and A. Fornes. 1973. Application of Automated Multispectral Analysis to Delaware's Coastal Vegetation Mapping. In: Proceedings of the 39th Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 512-519.

Overlay maps of Delaware's wetlands have been prepared, showing the dominant species or group of species of vegetation present. Five such categories of vegetation were used indicating marshes dominated by (1) salt marsh cord grass (*Spartina alterniflora*), (2) salt marsh hay and spike grass (*Spartina patens* and *Distichlis spicata*), (3) reed grass (*Phragmites communis*), (4) high tide bush and sea myrtle (*Iva* species and *Baccharis halimifolia*), and (5) a group of fresh water species found in impounded areas built to attract water fowl. In addition, major secondary species were indicated where appropriate. Small, representative areas of each of the major marsh regions were analyzed and enhanced to show detailed growth patterns not shown on the larger scale maps.

The mapping technique employed utilizes the General Electric Multispectral Data Processing System (GEMDPS) to analyze NASA RB-57 color-infrared imagery. The GEMSDPS is a hybrid analogue-digital system designed as an analysis tool to be used by an operator whose own judgment and knowledge of ground truth can be incorporated at any time into the analyzing process. The operator can combine his knowledge of the scene gained in the field with electronic analysis and (1) measure the spectral characteriscs of any chosen region of any size in the scene, (2) search the scene for regions with similar characteristics and once they are identified, enhance and store them, (3) modify the stored image if necessary to make it compatible with his knowledge of the area, and (4) read out the percentage of the total scene occupied by regions with the specified spectral signature. By repeating the procedure for other regions in the scene, the operator can quickly produce a composite of regions of interest. The result is a high speed cost effective method for producing enhance maps of a number of spectral classes--each enhanced spectral class representative of a vegetative species or group of species.

Klemas, V., D. Bartlett, W. Philpot, R. Rogers, and L. Reed. 1974. Coastal and Estuarine Studies with ERT-1 and Skylab. Remote Sensing of Environment. 3:153-174.

Coastal vegetation, land use, current circulation, water turbidity, and ocean waste dispersion were studied by interpreting ERT-1 and Skylab imagery with the help of ground truth collected during overpasses. Based on high-contrast targets such as piers and roads, the ERTS-1 multispectral scanner was found to have a resolution of 70-100 m, Skylab's S190A cameras about 20-40 m, and its

S190B camera about 10-20 m. Important coastal land-use details can be readily mapped using Skylab's imagery. On the other hand, the regular 18-day cycle of ERT-1 allow observation of important man-made and natural changes and facilitates collection of ground truth.

Latham, James P. 1973. A Comparison of Interpretation and Photogrammetric Methods for Delimiting the Mean High Water Position on Tropical Beach. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention, Lake Buena Vista, Florida. p. 803-818.

A determination of the position of mean high water on tropically-influenced beaches has recently been accomplished both by skilled interpretation of aerial photography and by the use of photogrammetric methods and tidal gauge measurements. When a time-series of aerial images are available, physical evidences of changing water lines can be interpreted to delimit the boundaries of public and private land. The fact that such a line can be drawn within a short time has advantages for public officials. More complex and time consuming methods based on photogrammetric measurement and a year of tidal gauge readings delay delivering a mapped line, and the data is applied to beach slope measurements from a photograph taken at only one instant of time to record a changing beach topography. This study compares the potentials of these methods illustrated by their applications of the beach in Florida.

Linde, A. F., and T. P. Janisch. 1977. Cover Mapping Wetland Areas with the Aid of 35 mm Low Altitude Color Photography. In: Wetlands, Ecology, Values and Impact. Proceedings of the Waubesa Conference of Wetlands held in Madison, Wisconsin. p. 388.

In 1959 research workers in the Wisconsin Department of Natural Resources began experimenting with oblique 35 mm aerial color photography to record habitat change and map aquatic vegetation on state owned wetlands. Techniques and equipment improved with time and experience. A motorized 35 mm Pentax camera utilizing 250 exposure rolls of film is now available which provides capabilities for low cost vertical photography in color. The best time to record species associations and monotypes as delineated by color patterns is after wetland vegetation has changed color following the first frosts. It was found that the best altitudes for obliques color photography was between 800' and 1500'. Vertical photography was accomplished between 1000' and 3000'. Altitudes above 3000' are not satisfactory since intensity and contrast in vegetation color patterns decreases with increasing altitude. Cost per acre of ground coverage for vertical photography varied between 0.1¢ per acre at 3000' altitude to 4.4¢ per acre at 1000' altitude.

Lukens, John E. 1968. Color Aerial Photography for Aquatic Vegetation Surveys. In: Proceedings of the 5th Symposium on Remote Sensing of Environment. Ann Arbor, Michigan. p. 441-446.

This paper discusses two applications of color aerial photography that are of interest to workers in water resources, especially those seeking a rapid and economical aid for the definition and modification of the ecology of large bodies of water.

Gross areas of species associations were mapped in water up to 18 feet deep in the Finger Lakes of New York, using techniques similar to those used in photo-soils mapping. The various factors that must be considered for photographing, interpreting, and mapping submerged and emersed vegetation are briefly discussed.

A second application of color aerial photography deals with the assessment of weed control measures for floating aquatics in Chesapeake Bay.

McEwen, R. W., W. J. Kosco, and V. Carter. 1973. Coastal Wetland Mapping. In: Proceedings of the Am. Soc. of Photogrammetry Fall Meeting. Lake Buena Vista, Florida. p. 926-937.

The U.S. Geological Survey is conducting a research project in the vicinity of Sapelo Island, Georgia, to investigate procedures for interpreting, delineating, and mapping coastal wetlands using remote sensing and photogrammetric techniques. The study area contains a variety of coastal marsh conditions, from saline to brackish, and extends from a mainland river through sea island marshes to the Atlantic Ocean. Orthophotoquads are prepared at 1:10,000 scale with a format of 2.5 minutes of latitude and 3.75 minutes on longitude. Coastal wetland boundaries and plant species associations are interpreted and delineated on the orthophoto base. In addition, the boundaries will be digitized for computer analysis. The primary objective is to evaluate the accuracy, time and cost for mapping coastal wetlands. The results of the investigation should be of value to Federal and State agencies with responsibilities for mapping or regulating the coastal zone.

Niedzwiadek, H. A., C. W. Greve, and H. Ross Tywell. 1978. The Wetlands Analytical Mapping System. In: Proceedings of the 44th Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 320-328.

The Wetlands Analytical Mapping System III is a computer-based system developed for the National Wetlands Inventory Project, U.S. Fish and Wildlife Service, for the purpose of producing a digital record with the classification and geographic location of wetlands in the United States. The system consists of a multi-photo analytical block adjustment program with interactive input and edit capabilities. This program is used for producing the exterior orientation parameters and other information required as input to the the digitizing process. The programs for digitizing produce the desired digital record of the wetlands on a geounit ("square" geographic parcel) by geounit bases. These programs are interactive and include the editing functions needed to create topologically valid data files to be incorporated into the National Wetlands Data Base. The data base software consists of programs to build and maintain the National Wetlands Data Base as well as provide map plots and answers to users via a query language package.

Pestrong, Raymond. 1969. Multiband Photos for a Tidal Marsh. Photo. Eng. 35(4):463-470.

A variety of multiband imagery, including nine-lens multiband imagery in the 400-900 millimicron range, panchromatic, Ektachrome and Ektachrome-Infrared photography, has been obtained for a tidelands area in San Francisco Bay. A technique for comparing their relative utility for specific geomorphic interpretations has been developed, whereby a subjective form of tracing analysis may be correlated with a more objective (and quantitative) scheme of selected microdensitometer traverses across the various negative and positive transparencies. The results suggest that the nine-lens multiband imagery is excessive, and, that for a similar use as that of the photos studies, could be reduced to four-lens imagery. The most useful frames are the 550-630 millimicrons bandwidth, the near-infrared, the Ektachrome color transparency, and the Ektachrome-Infrared transparency. Various utilities are suggested for each type of imagery, and increased experimentation by geologists with the microdensitometer is urged.

Pheiffer, W. J., R. A. Linthurst, and J. L. Gallager. 1973. Photographic Imagery and Spectral Properties of Salt Marsh Vegetation as Indicators of Canopy Characteristics. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Orlando, Florida. Part II. p. 1004-1016.

Primary production is a driving force in the functioning of the salt marsh ecosystem. An important factor in determining community photosynthesis is the light adsorptance, reflectance and transmittance by the plant canopy. The net effect of species difference, canopy architecture, leaf anatomy, pigment concentrations and edaphic factors were recorded *in situ* with a ISCO Model SR spectroradiometer. Biological and environmental factors were measured and their relationship to the spectral properties of the stands analyzed. *Spartina alterniflora* Loisel., *Juncus roemerianua* Scheele, *Salicornia virginia* L., *Sporbolus virginicus* (L) DC stands were studied.

Reese, Frances. 1976. Remote Sensing of Wetlands. A paper written in Civil and Environmental Engineering 552, University of Wisconsin-Madison, Madison, Wisconsin. 25 p.

A review of the literature concerning the use of black and white, color and color infrared photography, thermal infrared imagery and radar in mapping wetlands boundaries and species composition.

Reimold, Robert J., and Richard A. Linthurst. 1974. Remote Sensing-Wetlands. Meeting Preprint 2143, American Society of Civil Engineers, Nat. Mtg. of Water Resource Engineers. 20 p.

Coastal wetlands present an extremely harsh physical environment in which a variety of organisms survive. This is, despite their subjection to periodical wet and dry conditions as a result of tidal inundation and to alternating warm and cold cycles daily, the coastal wetlands provide one of the most biologically and ecologically valuable habitats presently known (Reimold and Linthurst 1973). Estuaries, for example, serve as a nursery ground for marine organisms by providing food and protection from larger predators. The wetlands also serve as a physical barrier to protect the coast from severe erosion during coastal storms and hurricanes.

There exists a variety of scientific methodologies to examine and study the importance and complexity of these wetland systems. Fornes and Reimold (1973), Reimold et al. (1972), and Thompson et al. (1973) have considered remote sensing technology as applicable to several specific wetland problems. It will be the purpose of this paper to summarize and examine multiple uses of remote sensing of wetlands and their potential applications to similar systems.

Robbins, J. Michael, and Marc J. Hershman. 1974. Boundaries of the Coastal Zone: A Survey of State Laws. Coastal Zone Mgt. J. 1(3):304-331. p. 392-401.

A survey of coastal state legislation reveals several types of statutes affecting activities occurring in coastal regions: coastal management statutes, wetland statutes, and shoreline statutes. Each coastal state has adopted methods to delineate coastal areas or features, whether an entire coastal zone, a limited feature such as wetlands, or shorelands. Boundary delineation is done according to linear measurements, political boundaries, roads and highways, vegetation, elevation, tidal flow, and other factors. An appendix is provided containing state statutory provisions relating to boundary delineation techniques.

Scarpace, F. L., R. W. Kiefer, S. L. Wynn, B. Quirk, and G. Friederichs. 1975. Quantitative Photo-Interpretation for Wetland Mapping. In: Proceedings of the 41st Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C.p. 750-771.

Analytical techniques and interactive computer programs for using color and color-infrared aerial photographs as a data source for mapping of a wetland in Wisconsin have been developed.

A portion of a color-infrared transparency (NASA RB-57 photograph) which contains part of the Sheboygan Marsh wetland system and the Kettle Moraine interlobate moraine system in Wisconsin has been digitized using a scanning microdensitometer. This color-infrared transparency was scanned separately through blue, green and red filters to extract density values from each of the three film layers, and, through an appropriate transformation, the analytical dye density of the film was determined for each point in the scanned area. These analytical dye density values were transformed through sensitometric calibrations into "equivalent exposure" values which are related to the scene reflectance. Using conventional photo-interpretation based on ground truth observations in selected portions of the test site, the rangs of "equivalent exposure" for each film layer for each resource type were determined using an interactive computer program. Once the user/interpreter has determined these values for each vegetative type, the vegetative types can then be automatically mapped for the entire test site.

A comparison is made between a computer-drawn vegetation map semi-automatically interpreted from a high-altitude, color-infrared photograph and hand-drawn vegetation map interpreted from the same photograph (and its stero-pair) by conventional photo-interpretation techniques using a zoom stereoscope and light table. The results seem to indicate that digital processing of film imagery is a cost-effective method of mapping large wetlands.

Scher, J. Scott, and Paul T. Tueller. 1973. Color Aerial Photos for Marshland. Photo. Eng. 39:489-499.

Color and color-infrared aerial photographs of water fowl habitats were studied to determine their usefulness for marsh vegetation evaluation. Attempts were made to determine the optimum film type, time of day, and time of year for best results. Both color and color-infrared films proved to be valuable for marsh evaluation. The larger scales (1:1,000) showed interpretation results with more accuracy than did smaller scales (1:10,000);

however, coverage was limited with large-scale photographs. Early morning photographs were found to be the most interpretable as sun-spot and wave effects were not prominent. The best time of year to photograph marsh vegetation was found to be late summer (August-September) when the submerged and floating plants were at a stage of maximum vegetative development.

Shima, Lurie Jessie. 1973. Wetland Vegetation Mapping Using Aerial, Color Infrared Photography. M.S. Thesis, The American University. Washington, D.C. 34 p.

Vegetation maps of dominant plant communities in a freshwater marsh on the Patuxent River, Maryland were prepared during the spring and fall of 1971-1972 and correlated with low altitude, color infrared aerial photography. Plant communities present were determined by field surveys, then compared to areas of homogeneous color on the spring and fall photography.

A tonal signature was determined for several plant communities because of their unique colors, saturations, and textures. Comparison of photography made in nearby marshes demonstrated that three of the twelve spring and five of the fourteen fall vegetation units mapped can be reliably identified.

Color fluctuations which produce a mottled effect on the photography constitute the color range of a tonal signature. These fluctuations are primarily caused by a quantitative variation of plant species within the unit but are also related to the growth cycle and habit, vigor of the plant species, and environmental conditions which affect the vegetation and turn the color of the recorded image.

Changes in the color, saturation, and texture of the spring and fall photographs indicated plant succession, growth habit, weathering, aging and vegetative decline.

Shima, L. J., R. R. Anderson, and V. P. Carter. 1976. The Use of Aerial Color Infrared Photography in Mapping the Vegetation of a Freshwater Marsh. Chesepeake Science 17(2):72-85.

Spring and fall vegetation maps were prepared from a freshwater marsh on the Patuxent River, Maryland. Low altitude, color infrared (IR) aerial photos were correlated with data obtained from field surveys. The vegetation units mapped refer to areas of homogeneous color on the photos. These areas of homogeneous color represent species associations or monospecific stands which produce a distinctive tonal signature.

Color fluctuations within an area having a distinctive tonal signature are primarily caused by a quantitative variation of plant species but are also related to the growth habit, vigor of the the plant species, and environmental conditions which affect the vegetation and in turn the color of the recorded image. Changes in the color over the growing season reflect plant succession, and vegetative decline. Tonal signatures of several plant associations were due to their unique colors, saturations, and textures. Comparison of photographs made in nearby marshes demonstrated that three of the twelve spring and five of the fourteen fall vegetation units that were mapped can be reliably identified.

Thompson, Donald E. 1972. Airborne Remote Sensing of Georgia Tidal Marshes. In: Operational remote sensing: an interactive seminar to evaluate current capabilities. Am. Soc. of Photogrammetry Fall Meeting. Falls Church, Virginia. p. 126-130.

Estuarine marshes of Georgia and all other marshes as well are essentially finite in area. They represent undeveloped land and are subject to pressures for manmade development of many sorts, especially as population increases. Scientists consider the marshes as a primary food production center for the esturine and continental-shelf marine ecosystem. Marsh grasses are the basis of the food production system--dead grass falls into the water, is broken up, washed out with the ebbing tides, and used by living organisms in the water.

To provide decision makers with a factual basis for assessing relative tidal marsh values, the University of Georgia Marine Institute at Sapelo Island is engaged in a series of research projects to measure marsh productivity quantitatively.

Airborne remote sensing of estuarine marshes, coupled with reliable ground truth data, provides the only feasible, economic means of assessing actual primary production. Work performed to date represents primary production measurements on a scale never before attemped. Integration of ground truth with photograhic and nonphotographic images represents a first in tidal marsh ecology.

Whitman, Ruth I., and Kenneth L. Marcellus. 1973. Textural Signatures for Wetland Vegetation. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Orlando, Florida. Part II. p. 979-992.

This investigation indicates that unique textural signatures do exist for specific wetland communities at certain times in the growing season. When photographs with the proper resolution are obtained, the textural features can identify the spectral features of the vegetation community seen with lower resolution mapping data. The development of a matrix of optimum textural signatures is the goal of this research. Seasonal variations of spectral and textural features are particularly important when performing a vegetation analysis of fresh water marshes. This matrix will aid in flight planning, since expected seasonal variations and resolution requirements can be established prior to a given flight mission.

Wynn, Sarah L., and Ralph W. Kiefer. 1978. Color and Color Infrared 70 mm Aerial Photography as a Monitoring Tool for Assessing Vegetation Changes in a Large Freshwater Wetland. In: Remote Sensing of Earth Resources Conference. Vol. VII, The University of Tennessee Space Institute. Tullahoma, Tennessee.

The Environmental Protection Agency is presently funding a three year study of the impact of siting a two-unit, 1000 megawatt coal-fired generating station in a 1600 ha wetland. Aerial photography has been obtained on a nearly monthly basis since 1971 covering the period of construction and a three year period after the initiation of operation. The 1971-1974 aerial photographs were 35 mm color and color infrared. The 1975-1978 photographs are 70 mm color and color infrared at scale ranging from 1:10,000 to 1:40,000. Detailed vegetation maps have been prepared from an extensive (four year) field survey effort and from human photo interpretation. The principal impact on the wetland vegetation is due to the extensive leaking of the 200 ha cooling lake built on a portion of the original wetland. Ground-water influx to the remaining wetland has increased by a factor of six, floating up and eroding much of the peat mat. Surface water levels are now consistent throughout the year. In addition ground-water temperatures are now out-of-synch with the normal temperature fluctuations by four to eight months. The result of the above is widespread destruction of the peat mat and accompanying change of wetland species from shallow water perrenials to more hydrophytic species in some areas and weedy annuals in others. Both human photo interpretation and extensive ground sampling data have been used to trace vegetation changes over time.

## WETLANDS--GENERAL INFORMATION

These references contain information on such subjects as wetland plant succession, wetlands classification, location of the mean high water mark, thermal alteration of aquatic ecosystems, wetlands as water purifiers, peatland evolution, the development of wetland soils, and marsh productivity.

Auclair, A. N., A. Bouchard, and J. Pajaczkowski. 1973. Plant Composition and Species Relations on the Untingdon Marsh, Quebec. Can. J. Bot. 51:1231-2147.

The purpose of this study was to identify significant species relationships and underlying ecological gradients characteristic of the Huntingdon Marsh, Quebec. In 1970 one hundred and seven 1-$m^2$ samples of plant biomass were obtained from the marsh in conjunction with environmental measurements. These data were later analyzed using principal-components analysis.

The marsh complex divided unambiguously into emergent aquatic and sedge meadow communities on the basis of distinct environmental and compositional differences. *Equisetum fluviatile, Scirpus fluviatilis, Eleocharis palustris,* and *Scirpus validus* were major species in the emergent aquatic community. Respectively, these species dominated 29, 25, 16 and 40% of 51 quadrats on a dry weight basis. Water depth accounted for almost one-third of the species variation in this community. Interaction between submerged and floating forms and competitive exclusion between dominant species explained much of the remaining species variance.

On a dry weight basis, *Carex aquatilis, Carex lacustris, Calamagrostis canadensis,* and *Typha angustifolia* dominated 36, 16, 16 and 11% of the 56 quadrats on the sedge meadow. As a group, *Carex* spp. dominated 63% of the quadrats. Disturbance related to chance perturbations, water depth, and the incidence of fire accounted for much of the variation in this community.

The organization of emergent and sedge meadow communities was discussed in relation to continuum and community concepts with particular reference to relative changes in discontinuity of species relationships across the environmental gradient.

Bay, R. R. 1968. The Hydrology of Several Peat Deposits in Northern Minnesota, U.S.A. In: Proceedings of the Third International Peat Congress. Quebec, Canada. p. 215-237.

A comprehensive peatland hydrology study has provided data on the climate, hydrogeology, water table levels, and run-off from forested peat deposits in northern Minnesota. Ground-water studies identified two types of hydrogeologic situations--perched bogs, independent of the underground flow system, and ground-water bogs, which were influenced by storage changes in the surrounding ground-water basin. Because the water tables are near the surface in undisturbed bogs, they are important in peatland hydrology. Bog water table levels indicated storage opportunity, and their reaction to precipitation was influenced in part by the type of peat material in the zone of active fluctuation. Run-off was not evenly distributed. Most of the annual water yield occurred in spring before June 1, while summer and fall water yields were generally low. Run-off was directly related to water level in the peat deposits.

Bay, Roger R. 1967. Ground Water and Vegetation in Two Peat Bogs in Northern Minnesota. Ecology 48(2):308-310.

Plant cover and water quality of bog waters are related to the surrounding ground-water flow systems in two bogs--one perched above and isolated from the regional ground-water system, the other nonperched and continuous with the regional system. The nonperched bog has higher pH, higher specific conductivity, and greater variety in plant cover than a perched bog.

Beard, Thomas D. 1969. Impact of an Overwinter Drawdown on the Aquatic Vegetation in Murphy Flowage, Wisconsin. Department of Natural Resources, Research Report #43. Madison, Wisconsin. 16 p.

A lowering of the water level on Murphy Flowage during the winter of 1967-68 resulted in a significant reduction in the distribution, relative abundance and acreage of aquatic vegetation.

The five species in greatest dominance before the drawdown were most affected, and collectively showed a reduction of 181.7 acres in the season after the drawdown.

Bedford, B. L. 1977. Changes in Wetland Vegetation Associated with Leakage from the Cooling Lake of a Coal-Fired Power Plant. M.S. Thesis. Univ. of Wisconsin-Madison, Madison, Wisconsin. 39 p.

This study was undertaken to investigate the possible environmental effects of a new coal-fired electric generating station on wetland plant communities adjacent to the facility's cooling lake. The wetland vegetation has changed quickly and dramatically due to changes in water temperature, water levels, and water flow, directly or indirectly caused by the presence of the cooling lake. The previously dominant sedge meadow communities have been replaced by emergent aquatic species or by annuals. An equilibrium state has not been reached.

Bedford, B. L., J. H. Zimmerman, and E. H. Zimmerman. 1974. The Wetlands of Dane County, Wisconsin. Dane County Regional Planning Commission in cooperation with the Wisconsin Department of Natural Resources. 581 p.

In this survey the emphasis was not on identifying and delineating wetland areas in the manner of a general inventory but rather on the wetlands, the surrounding upland, and watershed relationships as a unit, the unit necessary for management planning. This report is first a primer on the wetland ecosystem. It then applies this information to evaluating the wetlands of Dane County.

Bernard, John M. 1975. The Life History of Shoots of *Carex lacustris*. Can. J. Bot. 53:256-260.

Most shoots of *Carex lacustris* live for about 12-14 months, emerging in autumn, overwintering as shoots of up to 50 cm in length, and maturing during the next summer. Others emerge in early spring but both groups die in late autumn. A third class emerges in late July or August, grow to be over 50 cm in length, and die in late autumn, living only 2-3 months. Flower initials in this species begin growth in the September-October period and over winter while about 1.0 cm in length. The shoots that develop inflorescences are in general longer, heavier, and have greater basal diameter than those shoots which do not flower. More shoots flower if the water level in the marsh was high the previous year.

Bradley, W. G. 1972. Standing Crop and Productivity of Marsh Vegetation at Saratoga Springs, Ca. Research Memorandum, Desert Biome, U.S. I.B.P. RM 72-44. 14 p.

Estimates on standing crop were made by summing the products of average height of each species times its average percent cover. Biomass of marsh vegetation was determined by harvest methods.

Data from 1966-67 was included for comparison. Plant communities were described and arranged according to water availability as follows: Xeric Shrub with dominant species of *Larrea divaricata* (creosote bush), *Atriplex hymenelytra* (Desert Holly), and *A. parryi* (Parry's Saltbush); Phreatophye vegetation with dominant of Salt Cedar, inkweek, *Distichlis spicata* (salt grass) and Honey Mesquite; Salt Marsh vegetation dominated by *Phragmites* (Reed Grass), salt grass complex and *Juncus*.

The Xeric shrub communities consist of a single dominant species with two or three species making up 90% of the total cover and with average cover ranging from 2-4%. In Phreatophyte communities, found closer to the source of water and on salt flats seasonally covered by shallow water, 2-4 species make up 90% of the total cover which averages from 3-12%. The Salt marsh vegetation overlaps in some species with the preceding communities but shows an increase in diversity with 5-7 species having 5% or higher frequency, and average total cover increasing to 60 or 80%. Within the hydric area of the Spring, *Ceratophyllum demersum* and *Ruppia marituna* are present.

Soil salinity was measured and found to be highest in the Phreatophyte communities. It is suggested that soil surface salinity limits germination. Salt grass reproducing by vegetative means does well on these highly saline soils.

Standing crop estimates indices range from 0.89 for the salt flat communities to 95 for the bulrushes. The % area utilizied by the various communities ranges from 25% by open water and 23% by salt grass to 1% by tamarisk. Production of annuals was low, not surpassing 0.2% cover during study period. Perennials showed very slow annual growth increments. *Distichlis, Cressa, Phragmites, Scirpus* and *Juncus* made up most of the standing crop biomass in the marsh. A peak of 2833 kg/ha for the green-living parts of species occurred June through September.

Bruns, V. F. 1973. Studies on the Control of Reed Canary Grass Along Irrigation Systems. Agricultural Research Service. U.S. Dept. of Agriculture. ARS-W-3. 17 p.

Eleven separate experiments on the control of reed canary grass along irrigation channels were conducted near Toppenish, Washington, on the Wapato Irrigation Project from 1961 through 1964.

When applied repeatedly amitrole-T at 4 pounds/acre was as effective as amitrole at 8 or 12 pounds per acre and somewhat superior to dalapon at 15 to 25 pounds per acre in eliminating reed canary grass. However, even after eight treatments in 3 years, a few shoots still survivied at the water line. Such survival is a source of rapid reencroachment and spread. Initial fall applications of the amitroles or dalapon were superior to initial spring applications. Repeated applications of NH at 4, 6, or 8 pounds per acre did not suppress the growth satisfactorily in the zone immediately above the waterline. None of the herbicides appeared to translocate readily in reed canary grass.

Repeated applications of dalapon at 5, 10, or 15 pounds per acre did not suppress reed canary grass effectively along an irrigation channel. Dalapon at 20 pounds was about equally effective in controlling reed canary grass whether the herbicide was applied in 40, 80, 160, or 320 gallons of water per acre.

The effect of dalapon on reed canary grass when the herbicide was applied at 20 pounds in 100 gallons on water per acre on April 12 was not enhanced by the addition of kerosene at a rate of 0.5 percent (volume by volume). Further, the effect of dalapon was enhanced by the addition of 10 different commercially formulated surfactants at concentrations of 0.06 and 0.125 percent.

The optimum time for initially applying amitrole-T at 4 pounds per acre in the spring was about May 1 when the reed canary grass was approximately 3 feet high at the water line and still in the preheading stage. To maintain effective control during the season, two retreatments were necessary when initial treatments were made before mid-April, whereas only one retreatment was needed when initial treatments were made between mid-April and late-May.

Under favorable moisture conditions, fall applications of TCS at 100, 130 or 160 pounds per acre nearly eliminated reed canary grass. Seedlings of desirable grasses the following spring resulted in dense stands. However, the few surviving plants at the water line were growing profusely, were headed, and were spreading and lodging in the water by early summer of the 2nd year after treatment. Under dry weather conditions, the TCA treatments were less effective in eliminating reed canary grass and no seedlings of desirable grasses emerged the following spring. The ester of TCA at 12.5, 25 and 50 pounds per acre did not effectively control reed canary grass when applied in either a water or an oil dilutent. Treatments with paraquat at 2 pounds per acre controlled reed canary grass more effectively than treatments with diquat at 2, 4, or 6 pounds per acre. However, none of the treatments was practical for controlling sizeable infestations of reed canary grass along irrigation systems. Of the eight persistent herbicides applied to reed canary grass in late fall, dicamba produced toxicity symptoms most rapidly. However, dicamba did not completely eliminate the reed canary-grass at the waterline, even at 40 pounds per acre. Only atrazine at 40 to 80 pounds per acre, or isocil at

40 pounds per acre, eliminated all reed canary grass within 2 years after application.

Foliar applications of diuron at 4.8 or 9.6 pounds or bromacil at 2.4 pounds in 300 gallons of water per acre, plus surfactant at the rate of 0.5 percent by volume of water, did not control reed canary grass effectively.

Buma, P. G., and J. C. Day. 1975. Reservoir Induced Plant Community Changes: A Methodological Explanation. J. of Environ. Mngt. 3:210-250.

Reservoirs induce changes in established patterns of flooding, sedimentation, and ground-water fluctuations. These changes affect vegetation structure. This article explores a methodology to describe and map a flood plain vegetation complex downstream from a reservoir. A classification technique groups sampling units based on species compositions into plant communities.

Application of the technique to river systems before and after impoundment would permit monitoring of induced vegetation changes. Differences in plant community structure could then be related to changes in physical parameters caused by dams. Simultaneous monitoring of undisturbed systems in similar environmental conditions is necessary to form a basis of comparison for systems disturbed by river impoundments. Prediction of the major modifications attributed to river impoundment and their social, economic and ecological implications are necessary in comprehensive, integrated river basin planning.

Cain, Stanley A. 1928. Plant Succession and Ecological History in a Central Indiana Swamp. Bot. Gaz. 86:394-401.

This article describes conditions found in a half-drained swamp. All evidence points to the fact that the vegetation found in this area in the past was that found in undrained swamps. Lowering the water table caused *Sphagnum* to disappear, buttonbush to be restricted to a moat area, and *Calamagrostis* to spread. Two types of succession progressing from submerged aquatics to *Carex* and *Calamagrostis* and a *Typha succession* progressing from *Typha* to upland climax forest are cited.

Cowardin, Lewis M., and Douglas H. Johnson. 1973. A Preliminary Classification of Wetland Plant Communities in North Central Minnesota. Special scientific report--Wildlife No. 168, Washington, D.C., U.S. Dept. of the Interior. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. p. 1-33.

A classification of wetland plant communities was developed for a study area in north-central Minnesota in order to analyze data on waterfowl use of habitat that were gathered by radio telemetry. The classification employs features of several earlier classifications in addition to new classes for bogs and lakeshore communities. Brief descriptions are given for each community, and the important plant species are listed. Discriminant function analysis was used for 40 plant species. Seventy-five percent of the stands studied were classified correctly by this technique. Average probabilities of assignment to communities were calculated and helped to identify distinct and poorly defined communities as well as the relationship among communities.

Curtis, J. T. The vegetation of Wisconsin: An Ordination of Plant Communities. The University of Wisconsin Press, Madison, Wisconsin. 657 p.

*The Vegetation of Wisconsin* is a comprehensive study of the vegetation of that state. It is based on the study and analysis of data from 1400 stands and synthesizes these data into an exposition of the relationships of the vegetation of a large area. Southern forests, northern forests, grasslands, savanna and shrub communities, and lesser communities are each the subject of a chapter of this book.

Dix, R. L., and F. E. Smiens. 1967. The Prairie, Meadow and Marsh Vegetation of Nelson County, North Dakota. Can. J. Botany 45:21-58.

The objectives of the study were to determine the general phytosociological structure of the native prairies, meadows, and marshes of Nelson County, North Dakota; to establish relationships between this structure and factors of the physical environment; and to evaluate the relationships between the vegetation of Nelson County and True and Mixed prairies. Frequency values and environmental measurements on soil texture, salinity, pH, and an estimate of the drainage regime were obtained in 100 stands selected to represent the vegetational diversity within the county. The drainage regime proved to be the most important single environmental factor in determining the vegetation. A phytosociological drainage regime gradient was then established by assigning indicator values to selected species, and the behaviors of all species and environmental factors were displayed along this gradient. The vegetational display was then divided into six units: the uplands into high prairie, mid-prairie, and low prairie and the lowlands into meadow, marsh, and cultivated depressions. Each vegetational unit is described. Comparisons are made between each unit and the related vegetation in surrounding areas. It is concluded that Nelson County should be considered to be within the geographical area of the True Prairie, although the frequent occurrence of western grassland types and western species suggests that the county is within the tension zone between the True and Mixed prairies.

Frazier, B. E., and G. B. Lee. 1971. Characteristics and Classification of Three Wisconsin Histosols. In: Proceedings of the Amer. Soil Sci. Soc. Vol. 35:776-780.

On the basis of morphology, pH, and solubility in $Na_1P_2O_1$, three Wisconsin histosols were classified as (1) Fibrist, (2) Memist, and (3) Saprist.

Fiber content was found to be the single most useful characteristic in the classification of these histosols, and in quantifying various stages of decomposition and soil formation in histic materials. Fibric material consisted of 70% or more fiber as determined on a gravimetric basis, using a 140 mesh sieve to separate fibrous (> 0.1 mm) from non-fibrous (< 0.1 mm) material. The fiber content of hemic material ranged from 35 to 60%; sapric material contained < 15% fiber. Sodium pyrophosphate extract color (SPEC) is a useful parameter in the characterization and classification of histic materials.

Results of other analysis showed that the carbon content of the organic fraction was highest in the Saprist and lowest in the Fibrist. Oxygen and hydrogen contents were, in general, inversely related to fiber content. Total nitrogen appeared to be dependent on botanical composition of parent plants and microbial activity of the soil; the relatively high nitrogen content of certain subsurface layers may be related to illuvial deposition of mobile, nitrogen-containing substances. Mineral content was likely influenced by additional colluvial or colian sediments.

Frolick, A. L. 1941. Vegetation on the Peat Lands of Dane County, Wisconsin. Ecol. Mono. 11:118-140.

Ecological studies of the vegetation were conducted on the peat lands of Dane County, Wisconsin, particularly with respect to the nature of the plant successions. The secondary plant successions, brought about by a number of introduced, biotically controlled factors, namely, artificial drainage, cutting and grubbing of trees and shrubs, moving, grazing, burning, and concomitant soil disturbances are emphasized.

Peat lands comprise 52,288 acres or 6.8 percent of the total county area, nearly all located within the glaciated part of the county. The peat, chiefly of the water-deposited type, occurs in numerous beds of various sizes.

The natural drainage systems of the peat lands are in an immature stage of development. Between 1900 and 1926, approximately 40 percent of the peat land was artificially drained by 18 major projects.

The existing evidence is that the vegetation of much of the peat land at the time of settlement consisted of two principal types, the *Larix* consocies and the *Calamagrostis-Carex* associes. The *Larix* consocies is quasi-stable and accordingly recognized as preclimax.

The primary plant successions which have been of importance on the peat lands are the bog sere and the hydrosere. The bog sere was the most common type in the past, but has largely disappeared. Only relicts were found of a number of the developmental stages. The *Larix* consocies has been the most tolerant of the changing environmental conditions and it still occupies a small acreage of peat land. The primary plant succession is, at present, almost entirely of the hydrosere type because of more effective drainage. The *Populus-Salix* associes is recognized as subclimax to the *Quercus-Carya* association although conclusive evidence is lacking as to the true climax.

Introduced biotically controlled disturbance has been so general that much of the vegetation on the peat lands is now undergoing secondary succession. These successions are discussed and traced from the *Larix* consocies and the *Calamagrostis-Carex* associes stage of vegetation in relation to the factors of artificial drainage, cutting of trees, mowing, and grazing. Specific suggestions are made as to the most economically desirable ecological treatment of the various vegetational stages. The burning of the vegetation on wet or frozen peat has little effect on herbaceous vegetation but will usually prevent the ecesis of shrub and tree species. If the peat is dry, burning frequently results in various degrees of destruction of both peat and vegetation. Three degrees of burning are recognized, namely, superficial, medium and deep. The subseres following burning are discussed.

Other peat disturbances, the most important of which are the digging of drainage ditches and the consequent formation of ditch banks, play a role in modifying the vegetation.

Gibbons, J. W., and R. R. Sharitz. 1974. Thermal Alteration of Aquatic Ecosystems. American Scientist 62:660-670.

Heated effluents may function to enrich or to stress an ecosystem, depending upon the biological feature examined. However, the potential for negative impact on aquatic environments must not be underestimated. The ultimate consequences of the sometimes drastic alteration of behavior patterns and life-history phenomena in the surviving inhabitants of thermal areas have yet to be assessed. The relatively short time span of thermal field studies has not allowed thorough understanding of the biological chain reactions that may take place as physiological and genetic adjustments are made.

Grant, Robert R. Jr., and Ruth Patrick. 1970. Tinicum Marsh as a Water Purifier. In: Two Studies of Tinicum Marsh. The Conservation Foundation. Washington, D.C. p. 105-123.

A series of studies were done on Tinicum Marsh to evauate its role in reducing the pollution of Danby Creek. These studies were designed to determine: (1) the degree of degradation of Tinicum Marsh by pollution from Danby Creek; (2) the role of Tinicum Marsh wetlands in the reduction of nitrates and phosphates in Danby Creek water; (3) the role of Tinicum Marsh wetlands in the production of oxygen, and the reoxygenation of Danby Creek water; and (4) the productivity of the wetlands as measured by oxygen produced by a known area of swampland. Results showed that life in the marsh had been severly injured by organic pollution entering the marsh. The authors also conclude that the marsh plays a significant role in improving water quality.

Hanson, Herbert C. 1951. Characteristics of Some Grassland, Marsh and Other Communities in Western Alaska. Ecol. Mono. 21(4):317-339.

A study of vegetation changes associated with marsh drawdowns at Agassiz National Wildlife Refuge, Minnesota, revealed that the development of five types of vegetation on mud flats during the first year was influenced by seed availability, soil type and moisture, season and duration of drawdown, and the amount of stranded algal debris. The more an area combined early season drawdown, rich soil types, slow rates of mud flat drainage, and small amounts of stranded algae, the greater was the development of emergent aquatics.

In the second year of drawdown, most areas developed greater amounts of upland and shoreline weeds and fewer emergents. Areas originally exposed before August of the first year lost emergent cover during the second year, while the reverse was true of areas exposed later in the first year. Specific changes were influenced by density and composition of residual vegetation, soil types, and soil moisture. During longer drawdowns, the soil dried more completely, and over a 5-yr period nearly solid stands of willow developed.

Upon reflooding, mud flat and shoreline annuals were eliminated and marshes of cattails, soft-stem bulrush, sedges, spike-rush, willows and aquatic annuals developed in the first year. Specific development in subsequent years was determined by the nature of the residual vegetation and the depth of the restored water. Spike-rush and soft-stem bulrush were destroyed by flooding with over 15 inches of water in 3 yr and in any continuously flooded area in 4-5 yr. These species persisted only in shoreline evaporation zones. Common cattail and sedges were gone from continuously flooded areas in 4-5 yr and also persisted only in shoreline evaporation zones. "Hybrid" cattail remained unchanged in 25 in. of water throughout 5 yr of flooding. Two-year-old willows died in 2-4 yr in all depth, but willows on 4- to 5-yr-drawdown areas were killed only where flooded with 24 in. for 3-4 yr or 18 in. for 5 yr.

Depending on water depths and cover types, 1- or 2-yr drawdowns at 5- to 10-yr intervals are required to maintain emergent marshes at this refuge. Stands of hybrid cattail may be an exception.

Sago made outstanding growth and seed production in the first year of reflooding. Significant changes in soil chemistry and nutrient availability which probably occurred during drawdown, are suspected to be a contributing factor to this growth.

Until present limited knowledge of the consequences of drawdown is enlarged, the technique should be used only for specific purposes with proper control and study.

Helfgott, T., M. W. Lefor, and W. C. Kennard. 1973. Proceedings of First Wetlands Conference. The Institute of Water Resources. The University of Connecticut, Storrs. 95 p.

Papers were presented on wetland soils and geology, inland wetlands and ground water in eastern Connecticut, and wetland hydrology. They offer sound information on the types of soils and geologic conditions in which wetlands are found in a heavily glaciated area and the part wetlands play in the hydrologic cycle.

Heinselman, M. L. 1970. Landscape Evolution, Peatland Types and the Environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecol. Mono. 40(2):235-261.

The vegetation and peatland types of the Lake Agassiz Peatlands Natural Area are related to topography, waterflow patterns, water chemistry, and the evolution of the landscape as recorded by peat stratigraphy. Eight peatland types are distinguished: (1) microtrophic swamp, (2) weakly minerotrophic swamp, (3) string bog and patterned fen, (4) forest island and fen complex; (5) transitional forested bog, (6) semi-ombrotrophic bog, (7) ombrotrophic bog (raised bog), and (8) raised bog drain. Consistent differences in pH, Ca, and Mg were found between waters of contrasting peatland types. These differences agree with the division of peatland types by degree of mineral soil water influence (minerotrophy). A general topographic alignment of vegetation and peatland types agrees with the hypothesis of chemical controls. Vegetation types often have sharp boundaries related to changes in water properties, peat surface configuration and paths of waterflow.

Landscape evolution included five phases: (1) recession of Lake Agassiz about 11,700 yr ago, (2) organic sedimentation of local basins beginning 11,000 yr ago. Aquatic peats eventually covered 6% of the substratus; (3) development of fens, marshes and carr during the post-glacial warm-dry interval, beginning about 8,000 yr ago. These peatlands built the sedge peats that now cover 46% of the substratum. Paludification caused water tables to rise, and most water basins were overgrown; (4) invasion of minerotrophic swamp forests around about 5,000 yr ago as that climate cooled and precipitation increased. These forests built the basal forest peats that now cover 48% of the substratum. (5) Capture of part of the watershed by Northeast Brook about 3,100 yr ago, which caused a water table divide and mineral depletion, initiated sphagnum invasion, and led to development of the present ombrotrophoic raised bogs. As convexity grew, a sharp vegetation and chemical gradient developed along the limit of mineral soil water. Myrtle Lake rose steadily with paludification and now stands 11.8 ft (3.6 m) above the ridge 1 mile (1.6 km) north of the lake. Water tables rose 10-20 ft (3.0-6.1 m) over much of a 70-square-mile (181 $km^2$) area. This history does not agree with early concepts of succession which postulate a trend toward mesophytism with peat accumulation. The only "direction" here is a possible trend toward landscape diversity.

Heinselman, M. L. 1965. String Bogs and Other Patterned Organic Terrain Near Seney, Upper Michigan. Ecology 46(1):185-188.

Treeless string bogs and topographically oriented strips of bog forest have been discovered near Seney, Michigan, lat 46° 15 N, perhaps the southern limit of patterned bogs on the North American continent. Patterned ground has developed through paludification of a sandplain dotted with extinct dunes and sloping about 8 ft/mile. Many peatlands in Michigan, Minnesota, and Wisconsin have similar slopes and exhibit patterning in various degrees. Thus the principles that can explain the patterns and bog-forming processes at Seney may apply to large areas of forested and treeless peatland. Studies should be directed toward the interrelations between vegetation, water chemistry, local geology, peatland topography, peat hydrology, peat accumulation, and physical geomorphic processes.

Heinselman, M. L. 1963. Forest Sites, Bog Processes and Peatland Types in the Glacial Lake Agassiz Region, Minnesota. Ecol. Mono. 33(4):327-374.

This study was concerned with forest sites and bog processes on the Lake Agassiz peatlands in northern Minnesota.

The identity of the patterned bogs and fens of this region was established. Features that clearly mark the Lake Agassiz peatlands as members of this circumboreal group include string bogs (Strangmoor), topographically oriented forest islands, and fields of regularly spaced islands.

The decisive influence of water movement patterns on floristics and forest sites was underscored. The key seems to be the degree of isolation from mineral-influenced ground water. The course of such waters through bogs is often marked by water-track vegetation types. A tentative classification of peatland types is proposed.

Theoretical implications are discussed. Neither the processes of bog expansion nor the patterned bogs and fens of the Lake Agassiz region fit the classical picture of succession in the Lake States. Conclusions are that: (1) Few bogs in this region are the result of single successional sequence. (2) The bog types cannot be regarded as stages in an orderly development toward mesophytism. (3) Raising of bog surfaces by peat accumulation does not necessarily mean progression toward mesophytism. Such rises often cause concurrent rises of the water table and promote site deterioration. (4) The climax concept does not contribute to understanding bog history in this region.

Isirimah, N. O., and D. R. Keeney. 1973. Contribution of Developed and Natural Marshland Soils to Surface and Subsurface Water Quality. Water Resources Center, University of Wisconsin-Madison, Madison, Wisconsin. 30 p.

Preliminary qualitative estimates of the role of natural and developed marshland soils as a nitrogen or phosphorus source or sink were obtained by a limited ground and surface water survey of a marsh adjacent to Lake Wingra, near Madison, Wisconsin and by laboratory investigations of nitrogen and phosphorus transformations in soil samples from this marsh and from an acid bog in northern Wisconsin. Results are presented on the rates and pathways of these transformations. The results obtained by this investigtaion indicate that the marsh studied does not act as a significant nutrient sink. Thus while removal of the marsh by draining or filling might result in more N and P entering the lake, its presence does not appear to be a factor in lowering lake productivity. Nutrient input into the lake probably could be lowered by discharging storm sewers on mineral soil rather than on the marsh.

Isirimah, N. O., and D. R. Keeney. 1973. Nitrogen Transformation in Aerobic and Water Logged Histosols. Soil Science 115(3):123-129.

Wetlands (bogs, marshes, etc.) are a valuable natural refuge for birds, animals and fish. However, little is known of their value as a nutrient (particularly N and P) source or sink to the associated surface and groundwater supplies (Lee 1966). In recent years, many of these wetlands have been drained to make them suitable for agricultural or residential use. The aerobic conditions and associated higher temperatures accelerate decomposition of the organic soil matrix, and scattered evidence (Avnimelech 1971, Bentley 1969, Lee 1966) indicates that marshland drainage results in significant increases in the formation and subsequent leaching of $NO_3$-N to surface and subsurface waters.

In this work, samples of organic soils (Histosols) representing a wide range of botanical and chemical composition were subjected to incubation in the laboratory for 1, 3 and 6 months under water logged or aerobic conditions to estimate the N balance and N pollution potential of marshland soils under natural and drained conditions.

Jeglum, John K. 1971. Plant Indicators of pH and Water Levels in Peatlands at Candle Lake, Saskatchewan. Can. J. Bot. 49:1661-1676.

Quantitative data on vegetation, depth to water level, and pH of both moist peat and water from 113 stands of peatland near Candle Lake, Saskatchewan, are used to demonstrate relationships of peatland species to classes of pH and depth to water level, and to recognize plant indicators for the various classes. Weighted average and similarity coefficient techniques are used to estimate pH and depth to water level from total species lists and restricted lists of important species. Total species lists, combined with either weighted average or similarity coefficient techniques, yield indices with the highest correlations with the true values and the lowest standard errors of estimate. Depth to water level and pH are recognized as two important environmental correlates with floristic and vegetational variation in peatlands.

Jervis, Robert A. 1963. The Vascular Plants and Plant Communities of Troy Meadows--a Fresh Water Marsh in Northern New Jersey. The Bulletin--New Jersey Academy of Science 8(2):1-21.

1. Troy Meadows, a 1,800 acre inland fresh-water marsh, is located in the old basin of glacial Lake Passaic in the southeastern portion of Morris County, New Jersey.
2. Its history of use by white man began with the clearing of the land, formerly swamp forest, and subsequent drainage. Agriculture in the form of hay production followed, and failed, as drainage became less feasible, largely because of the subsidence of decaying peat. A retrogression to open water then must have occurred in places, reinitiating an aquatic succession.
3. The flora was sampled with regard to composition and distribution, using frequency determination based on 100 evenly spaced grid points.
4. The broad patterns of plant community composition and distribution were determined by extensive reconnaissance and the use of a cover-abundance rating for each species in a number of quadrats in stands of each community type.
5. Water depth, and depth and nature of the substratum were the major environmental variables investigated.
6. Troy Meadows contains at least 236 species of vascular plants, representing 67 families; among the best represented of which are the Cyperaceae, Gramineae, Compositae, Polygonaceae, and Labiatae. A total of 41 species were present at 25% or more of the frequency sampling points, among which the following displayed the widest distribution: *Impatiens capensis, Boehmeria cylindrica, Carex stricta, Peltandra virginica,* and *Lemna minor*.
7. Ten distinct plant communities were found to repeatedly occur in a complex mosaic throughout the marsh. These were mapped and the areal cover of each determined. The Cattail Community, covering almost 50% of the marsh, was the most important of these.
8. The following communities appear to be arranged along a decreasing moisture gradient: Open Aquatic, Cattail, Sedge Swale, Sedge-Shrub and Wet Meadow and Littoral. Other communities, influenced more in their distribution by physiographic factors, are the Floodplain and Riverbank communities which flank the Whippany River, and the Lotic and Streambank communities found in the water courses which feed the marsh.
9. A complex interaction of influences--including physiographic, edaphic, climatic, biotic, and, not the least, anthropogenic--is thought to be responsible for the present patterns of distribution of the flora and vegetation. Chief among these interacting influences in Troy Meadows appear to be: water level and its fluctuations; the texture, organic content and depth of the soil; alluvial transport and deposition of suspended materials; the mobility of disseminules of various elements of the flora; the availability of colonizable substrate and the range of tolerance of each species to the environmental spectrum encountered in its establishment in the community; animal utilization of vegetation; the influence of man's activities; ditching, fire and stream pollution; and chance.

Kadlec, John A. 1962. Effects of a Drawdown on a Waterfowl Impoundment. Ecology 43(2):267-281.

This report covers an evaluation of pilot drawdown on the Backus Lake flooding project in north-central lower Michigan and its effect on vegetation, waterfowl, soil, water and bottom fauna. The investigation included two growing seasons before and one after the temporary drainage during the summer of 1958.

Keefe, Carolyn W. 1972. Marsh Production: a Summary of the Literature. Marine Science 16:163-181.

A review has been made of studies of freshwater and saltwater marsh production. Reasons are discussed for the unusually high production of these communities when compared with terrestrial communities and phytoplankton. The role of marsh plants as food for consumers is also discussed.

Kraper, G. L., and H. F. Dulkbert. 1974. A Biological Survey of Kraft Slough. The Prairie Naturalist 6(3):35-55.

Kraft Slough is a moderately brackish, semipermanent marsh of approximately 950 acres in western Sargent County, eight miles east of Oakes, North Dakota. The marsh has been identified as one of 111 tracts in the states that contain representative biotic communities in a relatively undisturbed condition (Kantrud 1973). The purpose of this research was to provide detailed documentation of the wildlife and wildlife habitats occurring at Kraft Slough. This study was prompted by a proposed plan to create a reservoir in the Kraft Slough basin. Under this plan, 20 or more feet of water would be stored in the basin during the summer months to provide a water supply for irrigation of the Oakes Area-East Side; a segment of the Garrison Diversion Unit (Figure 1). The water surface area of the reservoir would be approximately 1440 acres at full capacity. Several large marshes occur a few miles east of Kraft Slough in an area that once formed the eastern arm of glacial Lake Dakota. Approximately 8,000 acres of wetlands including Burns Slough, Big Slough and Meszaros Slough are located in the glacial lake basin. Under the proposed plan, these wetlands would be drained and the basins would form part of the acreage to be irrigated from the reservoir developed at Kraft Slough (to be named Taayer Reservoir).

At present, ownership of the marsh is divided among state, federal and private concerns. The North Dakota Game and Fish Department owns 80 acres (Lake Taayer Game Management Area) and 480 acres are in Federal ownership. Public lands lie principally in the central marsh while five private landowners have peripheral holdings.

Lee, G. Fred, Eugene Bentley, and Robel Amundson. 1975. Effects of Marshes on Water Quality. In: Coupling of Land and Water Systems, A. D. Hasler, ed. Springer-Verlag, New York. 298 p.

Marshes and other wetlands in which there is a profuse growth of aquatic plants are common in many parts of the world. Wisconsin contains many thousands of hectares of marsh vegetation which typically stands from a half meter to several meters above the normal water elevation during the growing season. Water depths range from a few centimeters to several meters.

There is a certain flux of nutrients to the marsh from ground waters, surface flow and direct precipitation and gas exchange. The outflow is manifest in deposition of materials in the sediments, gas exchange and the transport in streams draining the marsh. The marsh is a complex hydrologic, chemical and biochemical system which can transform various elements into compounds that may improve water quality or have a deleterious effect.

Wetlands are often considered low-value land since in their normal condition they cannot be used for most agricultural activities or urban development. Also, some farmers have capitalized on the large amounts of nutrients stored within the marsh to develop muck farming after draining the marsh. The drainage of a marsh changes the release of aquatic plant nutrients. This chapter discusses results from the University of Wisconsin Water Chemistry Program on effects of marshes on water quality. Data on the chemical composition of waters discharged from several Wisconsin marshes as well as studies on the leaching of aquatic plant nutrients from drained marshes are primarily the results of studies by Bentley (1969) and Amundson (1970). Both of these students' theses should be consulted for additional details.

Madson, Carl R., et al. 1975. Wetland Losses Associated with Highway Construction in Western Minnesota. Paper presented at the 37th Midwest Fish and Wildlife Conference, Toronto, Ontario. 14 p.

Highway construction in the north-central United States threatens vast numbers of wetlands. As a part of highway construction, roadside ditches are often shaped so that runoff water reaching the right-of-way will move to the nearest creek or river. These ditches provide drainage outlets for fields and wetlands adjacent to the roadway, resulting in a loss of valuable wetlands. It is estimated that 99,292 acres of wetlands were drained in 19 counties of western Minnesota as a result of road construction. Recommendations are made to reduce these losses.

Millar, J. B. 1973. Vegetation Changes in Shallow Marsh Wetlands Under Improving Moisture Regime. Can. J. Bot. 51:1443-1457.

Changes in species composition and plant cover were studied in relation to moisture regime over a 10-yr period in 71 shallow marsh wetlands in the grassland and parkland regions of Saskatchewan. Decreases in density of the shallow marsh emergents *Polygonum coccineum, carex atherodes, Scoluchloa festucacea*, and *Eleocharis palustris* occurred with greater-than-normal water depth at the start of the growing season but 2 or more years of continuous flooding were required to eliminate emergent cover completely and convert the wetland to open water. Repeated autumn reflooding also resulted in complete elimination of emergent species. Changes in species composition occurred when basins were grazed and as vegetation reestablished after cultivation but no changes followed mowing or burning. *Alepocurus aequalis, Beckmannia syzigachne, Glyceria grandis*, and *G. pulchella* are designated as "disturbance" species on the basis of their response to soil-exposing events. Presence of small amounts of deep marsh emergents in shallow marsh wetlands is not considered a reliable indicator of wetter moisture regime. Species composition of rooted submergents in a wetland can be used as an indicator of its moisture regime. Shallow marsh wetlands in basins of 1 acre (0.1 ha) or less experienced little year-long flooding and converted to open water only under atypical conditions. Larger wetlands required basin depths in excess of 36 in. (96.4 cm) to have any amount of year-long flooding and to convert to open water. These basin size and depth criteria have applications in habitat evaluation by waterfowl managers.

Phillips, John. 1970. Wisconsin Wetland Soils. Wisconsin Department of Natural Resources. Research Report # 57. Madison, Wisconsin. 24 p.

This report describes wetland soils found in Wisconsin. It addresses soil morphology, soil relationships in wetland communities, and wetland soil properties in relation to land use.

Sears, Paul B., and Elsie Janson. 1933. The Rate of Peat Growth in the Erie Basin. Ecology 14:348-355.

There appears to be a period of maximum compression during the first 15 to 20 years, and after that much slower compression. Comparing the measurements, such as they are, for the first 70 years with those from peat certainly between 6,000 and 8,000 years old, it does not appear far from wrong to speak of a mean rate of peat accumulation of between 20 and 30 years to the inch for the past several thousand years, in the Great Lakes area. It is of interest to know that the application of this conventional rate to correlated deposits in Ohio has given a chronology for postglacial climates which is essentially that of the European periods of Blytt and Sernander as computer from clay varves by deGeer.

Seddon, B. 1972. Aquatic Macrophytes as Limnological Indicators. Freshwater Biol. 2:107-130.

Species of submerged and floating-leaved aquatic macrophytes have been placed in a series based on their patterns of occurrence in an ordination of floristic lists. Two chemical parameters from lake water analyses are correlated with the species assemblage in individual lakes. Trophic categories are defined on the quantitative chemical characteristics of lake waters. The range and limiting tolerance of solute content for many aquatic species are described and related to these trophic categories. Restriction towards eutrophic conditions is considered as an obligate relationship reflecting physiological demands. Some dystrophic and oligitrophic species are shown to have wide tolerance and are thought to be exclueded frm sites of higher trophic status by competition rather than physiological limitation.

Sheldon, R. B., and C. W. Boylen. 1975. Maximum Depth Inhabited by Aquatic Vascular Plants. The American Midland Naturalist 97(1):248-254.

*In situ* observations of submerged, rooted aquatic plants by a diver equipped with SCUBA have shown that the maximum depth distribution of a number of submerged species in a clear freshwater lake (Lake George, New York) is greater than previously reported. Maximum depth for any species was 12 m for *Elodea canadensis*. Water clarity is sufficient to allow 10% of the light intensity hitting the surface during midsummer to penetrate to this depth. The number of submergent species drops linearly from 38 to 1 m to one at 12 m. Data are presented for the maximum depth of occurrence for 28 vascular macrophyte species, and population densitities of these species at their preferred and maximum growth depths compared. The effect of several environmental parameters on depth inhabited by rooted aquatics is discussed.

Sherff, Earl E. 1972. The Vegetation of Skokie Marsh, with Special Reference to Subterranean Organs and Their Interrelationships. Bot. Gaz. 53:415-435.

This paper discusses general features of the vegetation at Skokie Marsh. Ecological factors studies were daily evaporation rate, depth of the water table, pH of marsh water and soil type. Lastly Scherff discusses subterranean organs of wetland species and their interrelationships. Root systems of different species can function in a complementary or competitive fashion.

Spence, D. H. N., and J. Chrystal. 1970. Photosynthesis and Zonation of Freshwater Macrophytes. I. Depth distribution and shade tolerance. New Phytol. 69:205-215.

The mean, range and standard deviation are given of the depths of water above the soil surface in which a number of *Potomogeton* species occur in Scottish lochs. Sun leaves of these species were produced in unscreened containers in a glasshouse and their rates of net $O_2$ production were measured at irradiances of from 1.34 to 7.08 cal/cm$^2$/hr in a Warburg apparatus, using Warburg buffer no. II as bathing solution. Using only leaves of species for which the rates appeared to be unaffected by buffer solution during the short experiments, it was shown that the shade tolerance of these leaves is correlated with the natural depth distribution of the species. This valid contrast in inherent photosynthethetic response between some deep water species (e.g., *P. praelongus, P. obtusifolius*) and some of shallow water (e.g., *P. polygonifolis*) indicates that light may be as important as substrate or competition in controlling the zonation of freshwater macrophytes.

Vitt, D. H., and N. G. Slack. 1975. An Analysis of the Vegetation of *Sphagnum*-Dominated Kettle Hole Bogs in Relation to Environmental Gradients. Can. J. Bot. 53:332-359.

Eight *Sphagnum*-dominated kettle bogs in northern Michigan were analyzed to elucidate vegetation patterns of both vascular plants and *Sphagnum* species in relation to measured bog gradients. Methods of both direct and indirect gradient analysis, including ordination and cluster analysis, were used. Community types as delineated in the ordination are discussed, including species distribution for *Sphagnum* and vascular plants. Segregation of community types followed gradients of pH, light, and calcium and magnesium ion concentrations. Two types of kettle-hole bogs were distinguished surrounding acid and alkaline bog lakes respectively, each with its own continuum of community types.

Vogel, Richard J. 1973. Effects of Fire on the Plants and Animals of a Florida Wetland. The American Midland Naturalist 89(2):334-347.

A total of 754 birds were recorded on a portion of a pond shoreline during 63 visits for 4 months following a controlled burn, while 236 birds were observed on an adjacent and comparable, but unburned, shore line. Only 5 of the 35 bird species encountered were seen more often on the unburned site. Fire-induced bird and mammal injury or mortality was unobserved even though the burn resembled a wildfire. Birds showed no fear of the fire and some were attracted to the smoking landscape. While some cold-blooded vertebrate mortality occurred, most herptiles survived, and alligators used the burned shoreline almost exclusively. Mammal populations of burned and unburned areas appeared similar 4 months after the fire.

Animal responses are considered related to the fire removal of the heavy grass mat that otherwise covered the water and soils and the foods contained therein, and physically impaired new plant growth. Burning also produced an earlier, more rapid and far more productive growth of wet-prairie plants.

Vogl, Richard J. 1969. One Hundred and Thirty Years of Plant Succession in a Southeastern Wisconsin Lowland. Ecology 50(2):248-255.

The post-glacial history of a marl and peat marsh contained evidence that early hydrarch succession may have been relatively rapid due to higher plant, as well as invertebrate animal, productivity. Pristine open marsh, sedge meadow, and wet prairie were held in quasi-equilibirum by alterations of floods during wet periods and fires during drought. Fires either checked terrestrial advancement or turned it back to earlier aquatic stages by organic substrate removal. Recent fire control and continued lowering of water levels hastened intermediate hydrarch succession by quickly and directly converting aquatic to terrestrial sites. A peat burn increased soil pH and soil nutrients, particularly the phosphates, and eliminated plant competition so that open marsh was immediately invaded by aspen forest, which will be converted to lowland hardwood forest. Recurring fires would perpetuate the aspen, but burning decadent aspen forest might originate true prairie. Although fire is usually catastrophic and retrogressive, it produced successional stability and even acted as a successional accelerator in this lowland.

Vogl, Richard J. 1961. The Effects of Fire on a Muskeg in Northern Wisconsin. J. of Wildlife Mngt. 28(2):317-329.

The effects of prescribed burning on the vegtation of Powell-Flambeau Marsh were studied during summers of the years 1959 through 1962. This area, located in north-central Wisconsin, is a hybrid community of open sphagnum bog or treeless muskeg and sedge meadows. The marsh is being managed to increase its productivity for wildlife, particularly for geese, ducks, sharptailed grouse (*Pediceetes phasianellus*), and white-tailed deer (*Odocoileus virginianus*). The burning was analyzed quantitatively using 14 paired stands, one member of each pair being an unburned control adjacent to the burned area. The vegetation within each stand was sampled using quadrat frequency studies. To evaluate the effects of fire, all plant species were divided into groups called increasers, decreasers, neutrals, invaders, or retreaters, depending on their responses to fire as reflected in average percent frequency changes. Results indicated that prescribed burning produces a conversion or retrogression from conifer swamp dominated by trees to open sphagnum bog or muskeg dominated by sedges and ericaceous shrubs. The muskeg may be changed further to northern sedge meadow, dominated by sedges and supporting a minimum of woody vegetation. This sedge meadow successional stage is considered more desirable than the other types because it allows the greatest movement, feeding, and nesting of game birds. Fire also improves game habitat by reducing the "rough" of woody and nonwoody plants, stimulating new and palatable growth, and increasing fruit and seed production.

Walker, B. H., and R. T. Coupland. 1968. An Analysis of Vegetation-Environmnt Relationships in Saskatchewan Sloughs. Can. J. Bot. 46:509-522.

This study examined the relationships between the distribution of herbaceous species and some of the major environmental factors in sloughs. Frequency distribution of species was studied in 64 stands. Environmental data, collected in 40 of these, included weekly readings of water level, fortnightly readings of pH and total dissolved solids in water, and texture and organic matter content of topsoil and subsoil. An association table of 24 leading dominants, arranged so that strongly associated species were close together, corresponded closely to their observed order along a moisture gradient. Environmental scalars were constructed to combine data on pH and total dissolved solids, as well as initial water depth and rate of water loss. The soil data showed very little association with species distribution. Synthetic scalars for water regime and water chemistry were plotted against one another to obtain an arrangement of stands. Plotting the frequency distribution of the leading dominant species over the environmental arrangement of stands showed most of the species to be strongly affected by the water regime and somewhat less affected by salinity. A few were restricted to a very narrow range of one of these factors, while others flourished in all segments of the environment. The relationships suggested by this analysis are largely in agreement with those suggested by the vegetation analysis alone.

Walker, B. H., and C. F. Wehrhahn. Relationships Between Derived Vegetation Gradients and Measured Environmental Variables in Saskatchewan Wetlands. Ecology 52(1):89-95.

Thirty-four relatively undisturbed stands of vegetation in shallow marsh, non- to slightly saline wetlands in south-central Saskatchewan were examined with respect to environmental influence on species distribution. Four environmental gradients account for the bulk of variation in the vegetation. They are, in decreasing order of importance, disturbance (dispite the fact that all stands chosen are relatively undisturbed), available nutrients, water regime and salinity. The greatest variation in the data from these stands as a whole is in their salinity, but this is not reflected in the vegetation. The correlation between water regime and available nutrients is negative. A number of other factors show minor correlations with the vegetation and with each other. The methods of prinicpal components analysis used in this study was a valuable aid in the interpretation of the data. It provides estimates of the proportions of (1) the variance associated with each principal component (2) the total variation in the vegetation data that can be assigned to variation in the environmental measurements.

Weller, Milton, W., and Cecil S. Spatcher. 1965. Role of Habitat in the Distribution and Abundance of Marsh Birds. Special report No. 43, Dept. of Zoology and Entomology, Ag. and Home Econ. Expt. Station, Iowa State Univ. of Science and Technology. Ames, Iowa. 31 p.

Severe drought during the 1950s produced dramatic changes in the vegetation of midwestern glacial marshes and in the abundance and distribution of marsh birds. Change in marsh habitat quality and quantity were studied in relation to bird populations in two small central Iowa marshes, Little Wall and Goose lakes near Jewell. General observations also were made on several larger marshes in northwest Iowa near Ruthven. These marshes were nearly dry in 1956 and became densely vegetated. With gradually rising water levels, plants flourished, and bird populations increased. Gross cover maps demonstrated the change in cover-water ratio and interspersion. Population estimates showed the changes in distribution and density of various species of marsh birds. During dry periods, only adaptable species such as redwinged blackbirds, were present. As water levels increased, densely vegetated areas were opened up by muskrat cuttings and yellow-headed blackbirds, coots, piedbilled grebes and least bitterns became established and increased in numbers. Maximum bird numbers and diversity were reached when a well-interspersed cover-water ratio of 50:50 occurred. By 1962, muskrats and high water had eliminated virtually all emergent vegetation with the result that all species except redwings were eliminated. A similar pattern occurred on marshes throughout Iowa, and similar changes have been noted throughout the glacial marsh region during this and previous post-drought periods.

Habitat changes permitted a measure of habitat preference and adaptability in several species. Populations shifted from area to area around the marsh as conditions changed because of muskrat cuttings. Redwings used shoreward vegetation and were the most tolerant of changing conditions. They utilized a higher percentage of brush and tree nest sites over land as emergent vegetation disappeared. Yellow-headed blackbirds were restricted to robust emergent vegetation standing in water but used only those areas adjacent to open water. Coots and pied-billed grebes both nested over water in cover of medium density with sizable adjacent water openings. Both were quite tolerant of open-marsh stages, and nest losses in coots at that time were often due to wind damage.

Black terns selected low, natural nest sites or built nests low to the water in sparse emergent vegetation where they were protected from wave action. Forster's terns nested in higher sites, such as active muskrat houses often in open-water areas, or built nests higher above the water than those of black terns.

The only competition noted was among shoreward nesting redwings and over water nesting yellowheads. Some interspecific chases were observed; yellowhead dominated redwings in the ideal yellowhead habitat, but redwings occasionally nested in yellow-head territories in small patches of vegetation not used by yellowheads.

Evolution of nest-site selection seems to have been influenced by general habitat of the ancestral stocks (terrestrial versus aquatic), by mode of locomotion (perchers, walkers, swimmers, and flyers) and by use of the major emergents (shoreward or water's edge). The vertical height and resulting "layers" of vegetation, their robustness and their relationship to water, influence species use and, thereby, species diversity.

Short-term fluctuations in marsh habitat conditions seem common in marshes as a result of change in rainfall and subsequent water level changes. The dry and wet, open stages are the least productive of birds, while the semi-marsh is ideal. Marsh birds have adapted to these conditions, and marsh bird populations are characterized by pioneering ability and mobility. A variety of marsh types and sizes of marshes in a given area are essential to the preservation of marsh bird diversity. Marshes are highly productive ecosystems characterized by dramatic short-term fluctuations. There are periodic invasions of terrestrial flora and fauna during dry years, while wet years produce a pond or lake-type community. The viewpoint of marshes as transient seral stages is challenged because of their duration of life and because of the equally dramatic changes that may occur in surrounding terrestrial biomes. It is suggested that a biome-type classification be applied to lakes, marshes, swamps, and bogs.

Westlake, D. F. 1967. Some Effects of Low-Velocity Currents on the Metabolism of Aquatic Macrophytes. J. of Expt. Bot. 18:187-205.

A prototype apparatus for making determinations of oxygen exchanges under controlled conditions of water flow is briefly described and some problems of technique are discussed in detail. The results include determinations of the photosynthesis and respirations of *Ranunculus pseudofluitans* and *Potomogeton pectinatus* in natural waters at velocities between 0.02 and 0.05 cm/sec, and some examination of effects of changes in irradiance and oxygen concentration. Flow was laminar at all velocities. At low velocities photosynthesis increased rapidly with velocity, but the rate of increase became less at higher velocities. The size of the effects varied with the metabolic capacity of the plant. For healthy shoots of *R. pseudofluitans* the maximum rate of photosynthesis was six times the probable static rate. These velocities are less than those in open water in streams, or even in the littoral of lakes, but may be comparable with the velocities within weed-beds.

Wharton, Charles H. 1970. The Southern River Swamp--a Multiple Use Environment. Bureau of Business and Economic Research, School of Businesss Administration, Georgia State University. 42 p.

Water quality data from both federal and state sources indicate that the Flint and Alcovy Rivers, with their adjacent swamps, apparently have the ability to clean pollutants from water. Swamp streams appear to eliminate human wastes and may remove toxic pesticides which, by way of complex food chains, might be dangerous to man, perhaps for miles below the source. Swamps induce deposits of silt and organic materials which become useful to the biotic community. The swamps have been called "giant kidneys". The swamp and its stream-channel seem intimately associated functionally, and appear to form a natural hydrogeobiological water treatment system. The value of the cleansing action of 6 miles and 620 acres of the Flint River Swamp is equivalent to sewerage treatment of a city of 50,000. Potentially, the Alcovy has over three times this ability, worth $990,000 per year. Dearmoring of the Alcovy's banks and the impairment of normal silt movement by channelization would cost an estimated $23,232 annually.

White, Keith L. 1962. Shrub-Carrs of Southeastern Wisconsin. Ecology 46(3):286-304.

Shrub-carr vegetation over its full range of variation in southeastern Wisconsin was quantitatively analyzed and the influence of origin, environmental factors, and disturbance on the vegetation was investigated. Plant composition was sampled in 76 stands distributed over 13 counties. A list of common shrub-carr species was derived by combining presence with frequency or intercept data. *Salix petiolaris* and *Cornus stolonifera* were the most common of 38 shrub species. The vegetation had three distinct layers, an upper dominant shrub layer, an intermediate tall herb, grass and sedge layer, and a low diminutive herb layer, but there was no stratification within the shrub layer. The pattern of plant distribution was very heterogeneous, due to irregularities in the soil surface and to disturbance. The response of common species to disturbance was indicated by arranging stands along a disturbance gradient. Most shrub-carrs in southeastern Wisconsin originated in the 1930s when shrubs colonized abandoned mowing meadows. The relative stability of the shrub-carr as a community appeared to be due to shrub resprouting after disturbance. Lowland forest undoubtedly invades the shrub-carr, although fire may kill seedlings and saplings and thus retard tree invasion.

## ENVIRONMENTAL MONITORING, ORGANIZING, AND POLICYMAKING

These references discuss environmental impact assessment, environmental decisionmaking, standardization of ecological surveys, quantitative ecology and impact assessment, regional environmental management, and wetlands management.

Amir, Shaul. 1976. Land Resources Assessment Framework: a Tool for Environmental Policy-Making. J. Environ. Mngt. 4:1-13.

Among the many difficulties that public agencies face in their attempt to develop and implement environmental policy, three are most important: (a) lack of a simple process for natural resource analysis and evaluation, (b) lack of a defined land use allocation criteria and (c) lack of data in a form that enables speedy environmental impact evaluation.

The purpose of this work, which is part of a large research project, is to suggest an analysis process and a planning framework that can be used in the development of conservation policy on a national or regional scale. The evaluation process suggested is composed of four main steps: (a) division of the area for analysis into land units, (b) assessment of the unit's conditions and reclamation potentials, (c) identificiation of natural values and (d) identification of impact areas. In addition to a detailed explanation of the framework, the paper includes the findings from the application of the framework to a 300 km$^2$ case study area in northern

Israel. From the initial application of the framework it seems a valuable tool for land resources planning and management for the development of conservation policy and its environment of proposed development plans.

Betters, D. R., and J. L. Rubingh. 1978. Suitability Analysis and Wildlife Classification. J. Environ. Mngt. 7:59-72.

The determination of wildland suitability for various uses and their proper classification for use is becoming increasingly important to planning. This article discusses an approach to constructing suitability indices for a number of various uses while considering many different criteria important to evaluating use possibilities. A multivariate statistical technique is then utilized to develop a hierarchical suitability classification. This classification offers a tool for analyzing the sensitivity of use suitability to level of classification.

Bisset, R. 1978. Quantification, Decisionmaking and Environmental Impact Assessment in the United Kingdom. J. Environ. Mngt. 7:43-58.

Increasing concern for the environment in the United Kingdom (U.K.) has led to demands that major policies and large-scale developments be subject to detailed impact assessment. A number of different methods have been devised for this purpose. Some of these involve the quantification and aggregation of impacts. A method developed in the United States (U.S.) which exhibits these characteristics is described and discussed. Also, a method which has been used in the U.K. is considered. It is shown that both these methods have serious disadvantages. In particular, they mask contentious items in an assessment thereby avoiding conflict between those in favour of a proposal and those against. Sections of the community in favour of certain policies or developments may therefore find these methods useful as a means of controlling public debate on the merit of proposals. It is concluded that open discussion of impacts would not be aided by these methods and that their use in the U.K. should be opposed.

Boyer, Donald E. 1973. A Case History of Remote Sensing Techniques in a Resource Inventory Process. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Orlando, Florida. p. 473-480.

Using remote sensing techniques and on-site investigations, a multidiscipline team conducted a physical, biological and visual resource inventory of the Oregon Dunes National Recreation Area. Inventory and interpretative data were developed on the common base of the geomorphic feature and its processes, further stratified by the plant communities. Their relationships to seasonal ground water fluctuation, wildlife habitat, aesthetic value and stages of dunal stabilization or degradation were established. An integrated report with interpretations was provided to a planning team as the foundation of the Recreation Development Master Plan.

Bradley, M. D. 1973. Decision Making for Environmental RRsources Management. J. Environ. Mngt. 1:289-302.

In a world of accelerating scientific and technological advance, of rapid social and economic appraisal and reappraisal of resources, increasingly complex choices have to be promptly made. The cost of faulty decisions weighs heavily, however, as society becomes increasingly concerned with broad environmental side effects, especially where these effects may be irreversible. Focus upon the forces and resistances acting upon the decisionmakers when questions of resource management are judged is needed to understand more completely the factors that contribute to decisions which ultimately reflect changes in the landscape, and which affect future public use and enjoyment of the environment.

Bunce, R. G. H., and M. W. Shaw. 1973. A Standardized Procedure for Ecological Survey. J. Environ. Mngt. 1:239:258.

A large-scale survey of semi-natural woodlands in Britain was carried out in the summer of 1971. The main aim of this project was to produce an objective, user-oriented classification of woodland ecosystems for use by practical conservationists. The shortcomings of traditional methods of ecological surveys are discussed briefly, and the paper then continues to examine the underlying principles which should govern the design of a valid and useful method of survey. The use of multivariate statistics provides the ecologist with an effective means of understanding complex variation, but, unless the data to be analyzed are standardized and obtained by a valid sampling procedure, the results will be of limited use. The final section of the paper provides an outline description of the method developed to meet the above requirements and used in the woodland survey.

Bush, P. W., and W. G. Collins. 1972. The Application of Aerial Photography to Surveys of Derelict Land in the United Kingdom. In: Environmental Remote Sensing: Application and Achievements, Eric C. Barrett and Leonard F. Curtis, eds. p. 169-181.

Local authorities are required to submit annually statistical information relating to the amount of derelict land which exists in their areas. This paper outlines one method of acquiring this information in cases where aerial photography is available, which could be utilized by planners having a modest knowledge of air-photo interpretation techniques. It briefly considers both the definition and classification of derelict land, and shows that air survey has substantial advantages over the traditional field survey: speed, accuracy, economy and the amount of information that can be collected in detailed surveys of derelict land.

Carter, Virginia and Doyle G. Smith. 1973. Utilization of Remotely-Sensed Data in the Management of Inland Wetlands. In: Proceedings of the Am. Soc. of Photogrammetry Symposium on the Management and Utilization of Remote Sensing Data. p. 144-158.

Remote sensing provides a powerful tool to meet critical management needs for inventory and classification of inland wetlands as well as for evaluation of the wetland role in the hydrologic cycle, identification of significant wetlands for wildlife preservation, and monitoring of wetland change. Remotely-sensed data are being presently utilized for wetland management in the Dismal Swamp (Virginia-North Carolina) and in wetlands of central and southern Florida.

Congress recently authorized the Department of the Interior to conduct a comprehensive study to establish the feasibility of preserving and protecting the Great Dismal Swamp. The Dismal Swamp is partly owned by the Department of the Interior and is of importance to the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, and numerous state and local organizations as well. High altitude photography flown by U-2 aircraft can be used for gross vegetation mapping, boundary determination, and selection of sites for intensive study. Low-altitude photography is useful for more detailed mapping. Black and white orthophoto quadrangels currently under preliminary stages of preparation in the U.S. Geological Survey will provide up-to-date maps of the Swamp at 1:24,000 scale. ERTS provides the big picture--the entire Swamp is visible on one ERTS frame--and permits observation of seasonal change and monitoring of significant ecological shifts. In southern Florida, ERTS is providing information for water management in the wetlands north and south of Lake Okeechobee where droughts place significant demands on water that is also needed for maintenance of the Everglades National Park. Water level and precipitation data are collected in near real time by the DCS (Data Collection System). These data are correlated with ERTS imagery that portrays the areal extent of standing water for prediction and management of water flow.

Curtis, L. F. 1972. Remote Sensing for Environmental Planning Surveys. In: Environmental Remote Sensing: Application and Achievements, Eric C. Barrett and Leonard F. Curtis, eds. Crane and Russak, New York. p. 89-109.

The remote sensing techniques available for environmental monitoring are discussed with special reference to remote sensing platforms and sensing systems. Examples of remote sensing studies using infra-red line-scan and multiband photography in Britain are described. Particular applications of infra-red line-scan to shelter-belt studies in rural areas are outlined. Multiband photograhy is examined in respect of its potential application to land-use, soil and vegetation studies. Illustrations of the use of image enhancement by colour additive methods are included, together with examples of densitometer measurements from multiband photography.

DeGloria, S. D., S. J. Daus, and R. W. Thomas. 1975. The utilization of remote sensing data for a multidisciplinary resource inventory and analysis within a rangeland environment. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 640-659.

The Bureau of Land Management (BLM) is charged with the multiple-use management of National Resource lands which encompass over 180 million hectares in the eleven western states and Alaska. Due to the vastness of these lands, the BLM realizes the need to integrate remote sensing applications technology into their planning system. Various remote sensing techniques were utilized to produce map products for assessing the applicability of these techniques to the BLM system. Techniques include manual analysis of LANDSAT-1 and high-altitude, color-infrared photography, and the application of discriminant analysis and multi-stage sampling techniques in a human-machine interactive analysis of single-date LANDSAT-1 digital tape data. Manual analysis of single-date LANDSAT-1 imagery provided landscape vegetation resource maps. The high-altitude photography was utilized to produce vegetation-type and "sensitive area" maps for two BLM Planning Units. Acreage and productivity estimates by major vegetation type were generated using multistage estimates from sampling units on LANDSAT-1 digital data, high-altitude photography, very large-scale aerial photography, and systematically collected ground data. The information generated will provide the BLM with timely and cost-effective information regarding the vegetative resource.

Dirschl, H. J., and D. L. Dabbs. 1972. The Role of Remote Sensing in Wildland Ecology and Environmental Impact Studies. In: Proceedings of the First Canadian Symposium. Ottawa, Ontario. p. 339-344.

Public and industrial interest are increasingly focused on northern environments which until recently have remained relatively unaffected by the technological era. Formidable problems of environmental protection result from major resource developments involving massive environmental alterations. The magnitude of these problems makes it imperative for ecologists to critically examine the investigational methods and procedures which they have traditionally used. In searching for a "common denominator" in all wildland ecological and environmental impact studies, we are led to the realization that landform exerts a fundamental control over local environment. Aerial photographic imagery provides a bird's-eye view of the landscape, facilitating the identification and delineation of landform units with which biological phenomena can be correlated.

Two examples are dicsussed where air photo interpretation has proved to be the most efficient means of study. Sequential aerial photography in the Peace-Athabasca Delta has facilitated an understanding of the complex deltaic processes and the study of plant succession and wildlife habitat changes resulting from a recently modified river regime. Air photo interpretation is the basis for extensive renewable resource inventories and terrain sensitivity studies now underway in the Mackenzie River Valley. The proposed construction of a natural gas pipeline, and possibly an oil pipeline, across northwestern Canada and Alaska has prompted ecological studies of vast Arctic and Subarctic areas. The manner in which air photos are being used as a working tool in these studies is discussed.

Doiron, Linda N., and Robert T. Wilson. Remote Sensing Techniques for Wildlife Inventories in the Coastal Marsh. In: Remote Sensing of Earth Resources Conference. The University of Tennessee Space Institute, Tullahoma, Tennessee. Vol. III. p. 685-696.

The coastal marshes of Louisiana are recognized as a rich and important resource which must be managed and used wisely. Management of the muskrat (*Oncatra zibethicus*), a major inhabitant of the marsh is an important key in wise marsh management. In order to manage the muskrat, population and distribution information is of vital importance. Color infrared aerial photography can possibly play an important role in providing this necessary information.

Everhardt, L. L. 1976. Quantitative Ecology and Impact Assessment. J. Environ. Mngt. 4:27-70.

Some of the issues of environmental impact assessment are reviewed from the point of view of quantitative ecology, and on the assumption that evaluations are done on a site by site basis. Two approaches are examined in detail, one being the traditional experimental approach and the other one attempting to predict impacts from data and models. The experimental approach suffers from the fact that there is no true replication. A pseudodesign is proposed, employing pre-operational data on a site and a control area constrasted to post-operational data on both areas, and substituting replication in time for true replicate areas. Even so, the limitations of animal census methods and substantial variability make it doubtful that any but major changes can be detected experimentally. Predictive techniques, employing methods developed primarily for fisheries management, may be preferable to the baseline and monitoring concept. However, these methods have not yet been adequately adapted to the present purpose and some gaps can be foreseen. One is the lake of knowledge about stock-recruitment, when the recruits are at very early life history states. The population regulation problem is identified as a major issue in impact evaluation. Questions are raised as to the utility of data or productivity and species diversity, as presently used. It is concluded that we must take stock of what has been done in impact evaluation, and attempt to reach a concensus as to future methodology.

Fischer, D. W., and G. S. Davies. 1973. An Approach to Assessing Environmental Impacts. J. of Environ. Mngt. 1:207-227.

The analysis proposed in this paper is designed to permit the assessment of the likely impact of man's development and management activities on the environment. The complete assessment consists of four sequential steps: (1) identification of planned and induced activities, (2) identification of relevant elements of the environment likely to be altered, (3) evaluation of initial and subsequent impacts, and (4) management of beneficial and adverse environmental impacts that are generated by the planned and induced activities over time. The emphasis in the paper is upon the identification and evaluation of environmental impacts because this subject sets the stage for subsequent management of the environment. Three steps are used to identify and evaluate environmental feasibility. These are briefly illustrated with examples from forestry and water management. The discussion of identification and evaluation assumes that engineering and economic evaluations are being done simultaneously along with the environmental impact analysis. The environmental analysis is to be accomplished by a small multidisciplinary team which would guide, co-ordinate and interpret environmental studies being done by various technical specialists. The paper also includes a brief review of environmental impact assessment methods developed primarily in the United States.

Fisher, A. C., and J. V. Krutilla. 1974. Valuing Long Run Ecological Consequences and Irreversibilities. J. of Environ. Econ. and Mngt. 1:96-108.

In this paper we consider the special nature and implications, for economic theory and policy, of resource uses that involve adverse effects on the physical environment that are difficult or impossible to reverse. Distinctions are drawn between reversible and irreversibly activities, between replaceable and irreplaceable resources. The existence of an "irreversibility premium" is demonstrated under certain plausible conditions, including uncertainty and shifting time perspective.

Garluskas, A. B. 1975. Conceptual Framework of Environmental Management. J. Environ. Mngt. 3:185-203.

This paper explores the conceptual framework of environmental management. Based on ecological principles, environmental management produces the least environmentally disruptive decision-making path by interdisciplinary integration of multi-disciplinary knowledge. Environmental management is the intellectual force that can synthesize specialized views and objectives and merge them to guide the human society toward a compatible existence with nature. In its generalistic approach, environmental management visualizes the whole as well as its parts. Through an environmental management framework the relationships and interdependencies can be viewed and assessed in total perspective. The recognition that man-made artificial systems exert a spectrum of stresses on the environment is a prerequisite for the use of the environmental management framework. In its philosophy environmental management is holistic, stressing ecological complexity and interdependency of man and nature. Functionally, it is a businesslike approach to controlling environmental disruption.

Glenn-Bird, S. J. 1972. Remote Sensing Evaluation of Environmental Factors Affecting the Developmental Capacity of Inland Lakes. In: Proceedings of the First Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 755-764.

The objectives of this paper are first, to point out the multidisciplinary aspects of remote sensing, and second to apply them to a specific investigation concerning the developmental capacity of the inland lakes of Ontario. Consequently, the paper is presented in five sections, as follows:

1. Multidisciplinary aspects of remote sensing.
2. Purposes and phasing of lake capacity study.
3. Regional uses of remote sensing for lake capacity study.
4. Evaluation of parameters using remote sensors.
5. Specialized studies required in remote sensing.
6. Conclusions and recommendations.

Goldstein, Jon H. 1971. Competition for Wetlands in the Midwest: an Economic Analysis. Resources for the Future, Inc. Washington, D.C. 110 p.

This study was written to provide a social and economic model to evaluate the many values of wetlands. Goldstein is concerned with "...private and social values in the wildlife sectors with the benefits of waterfowl population maintenance being borne largely by farmers." Goldstein discusses the costs incurred in draining wetlands as well as the government agricultural incentives to drain wetlands; wetlands as breeding habitats; and lastly the distribution of hunting land in Minnesota. This study addresses the incentive structure for having a more efficient allocation of wetlands in the central and Mississippi flowages.

Gupta, T. R., and J. H. Foster. 1973. Institutional Framework Affecting the Use of Inland Wetlands in Massachusetts. The Cooperative Extension Service, University of Massachusetts. U.S.D.A. and County Extension Services. 39 p.

This study discusses the relationship between wetlands and man as conditioned primarily by institutional considerations. Emphasis is on the description of forces affecting wetland usage and the social value of such lands. Forces studied include the laws governing wetland usage; nature of ownership, ownership costs such as taxes and goals and plans of the owners of wetlands. Also considered are the activities of groups such as real estate dealers; construction firms and the influence of public opinion. The study is based on the survey of wetlands in fourteen Massachusetts towns and cities. Communities were selected on the basis of a judgment sample so as to represent variations in topographical, geological, social and economic forces as well as the dispersion of different types of wetlands throughout the state. Forty-five wetland owners located in these communities were interviewed during the summer of 1971 using a structural questionnaire. Discussions were arranged with the tax assessors, real estate agents, contractors, members of conservation commissions in these plus a few additional towns. Discussions were also held with the officials of the Massachusetts Department of Natural Resources (DNR) to develop an understanding of the laws governing wetland usage and problems in their implementation. Some public hearings dealing with the question of alteration and/or preservation of wetlands were attended to get a feeling for public opinion on the matter.

Initial assumptions were:

(1) There is a general attitude of indifference towards wetlands amongst people in general and wetland owners in particular.

(2) The higher the tax liability on wetland, the greater the chances of its alteration.

The following discussion is divided into five sections dealing, respectively with the (1) laws governing wetland usage; (2) pattern and length of wetland ownership, and the owner's attitudes towards the same; (3) assessments and taxation of wetlands; (4) owners' opinions on wetland taxes; and (5) some suggestions for alternative institutional arrangements.

Haslam, S. M. 1973. The Management of British Wetlands. I. Economic and Amenity Use. J. Environ. Mngt. 1:303-320.

Wetlands are an important aesthetic amenity much enjoyed by many visitors. They also bear a wide variety of saleable products, including thatching reed and sedge, marsh hay, litter, craft materials, peat and turf, and can be profitably let for shooting, fishing, and grazing. Most lowland wetlands have been managed for their exploitable products for many centuries and can be maintained with these communities only by the continuation of this management. The addition of paying visitors should provide sufficient funds to pay for the management. Intensive recreation does disrupt a habitat, but many uses can satisfactorily co-exist on a large, or a series of small, wetlands.

Haslam, S. M. 1973. The Management of British Wetlands. II. Conservation. J. Environ. Mngt. 1:345-361.

Conservation is management for biological quality. In general, if the vegetation is managed to the desired end, the appropriate animal life will follow without special treatment (though macrofauna may need greater freedom from disturbance). The variables most usually controlled are water regime, cutting, burning, and grazing. Much diversity is obtainable by using different combinations of these factors, which are the factors under which most lowland wetland communities have evolved and to which they are adapted. Examples are given of relations between communities or species and management variables.

Heyland, J. D. 1972. Vertical Aerial Photography as an Aid in Wildlife Population Studies. In: Proceedings of the First Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 212-236.

The advantages and disadvantages of visual censuses of wildlife populations are discussed. It is noted that oblique photographs have limited use in census procedures and are most useful for panoramic, illustrative purposes. It is suggested that vertical photography provides the best method of censusing many animal and bird populations. Vertical photography of the population of Greater Snow geese, during the spring and fall migration periods along the St. Lawrence River, has made it possible to accurately census the geese, distinguish young from adults, to separate family units, to determine ranges of brood sizes and mean broods and to obtain age ratiios. Experimental vertical photography has shown that several species of waterfowl, some terrestrial ungulates, narwhal, and beluga could probably be accurately censused using this technique.

Johnson, B. G. 1974. Developing Data for Environmental Impact Studies. J. of Tech. Asso. of the Pulp and Paper Industry. 57(9):81-84.

Environmental impact studies leading to the preparation of the Environmental Report have become a common undertaking associated with almost every private or governmental activity that could potentially affect the environment. Considerable effort is being devoted to assuring that the environmental impact of a proposed development is kept at a minimum. The objective of the impact study is to develop a sufficient data base to permit a meaningful assessment of environmental conditions that exist on and in the immediate vicinity of the proposed site. With these data, the best judgment can be made relative to the expected impact from construction and operation of the planned facility prior to undertaking the project. This predictive information is reviewed by appropriate regulatory agencies and the public and approval to proceed is given if there is assurance that the environment will be protected. The impact study also produces the data base to which subsequent preoperational and operation data can be compared to confirm that the initial predictions of environmental impact are valid. Consequently, defining the project scope, implementing the study plan, evaluating the results, and preparing the Environmental Report are essential steps to sound environmental planning.

Kirby, C. L., and P. I. Van Eck. 1977. A Basis for Multistage Forest Inventory in the Boreal Forest Region. In: Fourth Canadian Symposium on Remote Sensing. Quebec, Canada. p. 72-94.

Developments in the interpretation of LANDSAT imagery, ultra-small and large-scale aerial photography and their application in a multi-stage sampling design are presented. Merchantable softwood area determined by means of computer-assisted interpretation of a winter LANDSAT scene correlates highly with wood volume estimates obtained from aerial photographs and ground samples. As a result the amount of sampling required in succeeding stages is reduced. Ultra small-scale, infrared color aerial photography is evaluated as a tool for estimating stand volumes and for the preparation of forest cover and soils maps; it is found to be accurate and efficient. It may not be used in primary and succeeding stages of the design, however. Equations for predicting individual tree diameter and volume from measures on large-scale aerial photographs are developed. The test of a multistage sampling design indicates that accurate volume estimates for large areas may be obtained especially when measurements from LANDSAT imagery and small and large-scale aerial photographs are used to provide a dynamic information system.

Larson, Joseph S. 1975. Evaluation Models for Public Management of Freshwater Wetlands. Proceedngs of the 40th North American Wildlife and Natural Resources Conference. p. 221-227.

State statutes protecting the public values of freshwater wetlands have been in effect for nearly 10 years in several northeastern states. Early versions of statutes gave the responsibility of administering these laws to a state natural resource agency. As experience has been acquired, the tendency has been to shift this responsibility to local agencies, such as Town Conservation Commissions. These are local boards like health and planning boards, and they are responsible for regulating the use of wetlands. In some cases they are empowered to acquire land for conservation purposes.

In Massachusetts alone, 351 separate local commissions and one state appeal agency are examining requests to alter or destroy wetlands. Many commissions are buying wetlands to protect their natural values. In each case value judgments are being made and priorities are being set. There exist few guidelines for evaluation of freshwater wetlands and as competition for land in highly urbanized states grows keen the critria used to justify protection of a wetland are being examined critically by developers and natural resource agencies alike.

This report presents highlights of results of a team research effort at the University of Massachusetts to develop a better basis for decision-making in wetland preservation and to attach economic values to freshwater wetlands. Early progress of our work was reported to the Thirty-Sixth North American Wildlife and Natural Resources Conference (Larson 1971) and this is a summary of our completion report (Larson 1975).

Lillesand, T. M., and W. P. Tully. 1975. Remote Sensing, Water Quality and Land Use: From the Obvious to the Insidious. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 582-615.

The influence that land use exerts on water quality ranges from the obvious to the insidious. Two case study examples are presented which demonstrate the utility of remote sensing in monitoring land use and water quality in "obvious" and "insidious" scenarios, respectively. The former is typified by a photographic and thermal study of Ononodaga Lake in Syracuse, New York. The shoreline of this lake is urbanized, industrialized; these shoreline land uses dominate the water quality of Onondaga Lake, which is highly polluted. The later scenario is exemplified by Chaumont Bay, located along the eastern Lake Ontario shoreline. Non-point sources of pollution associated with upland land use characterize this region. In such cases, improved land use planning and control, in the context of water quality preservation and restoration, entails increased linkage and synthesis of land use, water quality and hydrologic data. The role remote sensing can play in providing this linkage and synthesis is presented conceptually.

Milfred, C. J., D. E. Parker, and G. B. Lee. Remote Sensing for Resource Management and Flood Plain Delineation. Photo. Eng. 35(10):1059-1063.

Boundaries of rare floods, such as a 100 year recurrence interval flood which is widely use for planning and regulatory purposes, are ordinarily plotted by engineering procedures. In this study, flood plain boundaries were interpreted on (1) panchromatic, and (2) color aerial photographs along a stream in a glaciated area of southern Wisconsin. The accuracy of these boundaries was determined by comparison at 29 cross sections with those of an Intermediate Regional Flood plotted by the U.S. Army Corps of Engineers. Boundaries on both types of photography agreed with the engineering boundary at 28% of the cross sections, were within 100 feet at 67% of the cross sections, and within 300 feet at 95% of the cross sections. Flood plain boundaries were most accurately delineated where physiographic landforms were well defined. The results indicate that airphoto interpretation can be a useful tool to delineate flood plain boundaries where the lack of hydrologic data, time and funds prohibit plotting boundaries by traditional engineering methods.

Mitnick, B. M., and C. Weiss, Jr. 1974. The Siting Impasse and a Rational Choice Model of Regulatory Behavior: an Agency for Power Plant Siting. J. of Environ. and Econ. Mngt. 1:150-171.

Reasons for the current siting impasse, including participatory activism, regulatory failure, the multiplication of considered interests, and the "investigative careat" are reviewed, and the existing logic of regulator behavior, viewed as a rational choice model, is summarized. Three sets of goals for agency participants are identifieid: personal goals of agency decisionmakers, organizational goals of the agency as a whole, and goals of agency clients; and the incentive system of a new administrative agency structured so as to make satisfaction of these goals contribute toward informed and impartial decision-making. Major structural components of the agency would be a Director, a Corps of Examiners, counsel(s) for special interest(s) of special merit, and Public Counsel, and a Research and Information Office. The model is applied to the case of a regional or state-level agency to handle power plant siting.

Moore, W. C. 1972. Remote Airborne Sensing of Water Pollution: Rideau River Drainage Basin. In: Proceedings of the First Canadian Symposium on Remote Sensing. Ottawa, Ontario. p. 211-233.

The Rideau River drainage basin has been identified by the Economic Council of Canada as one of four basins in eastern Ontario and Quebec significantly affected by water pollution. In addition the basin's proximity to the nation's capital helps make it an attractive region for recreation and tourism, but the water quality of the Rideau system is slowly deteriorating and the aesthetic values of the system are being seriously degraded. To monitor the situation, an extensive water-sample analysis program is underway, but much more is required before meaningful and effective action can realistically be planned to correct the water pollution problem. Multispectral remote airborne sensing can rapidly provide accurate, detailed information for a better understanding of the complex environmental interrelationships that are so important to water pollution control. It is also important that airborne sensing imagery serves as a focus, or a synthesis, of multidisciplinary teams on the basis of whole drainge basins. In this paper, multispectral imagery from three different reaches of the Rideau system are examined to evaluate remote airborne sensing techniques for investigating water pollution in the Rideau River drainage basin.

Munn, L. C. 1975. Problems in Employing Remote Sensing in Environmental Impact Studies. In: Proceedings of the Third Canadian Symposium of Remote Sensing. Edmonton, Alberta. p. 367-370.

There is a growing concern among Canadians for the deterioration in the quality of our natural environment. The impact of many activities on the biophysical resources must be understood and considered in all phases of project planning, development and operation. The planning process is discussed and it is suggested that the late consideration of environmental concerns is a major deterrent of the use of remote sensing in impact assessment. Biophysical processes are interdependent one on the other and require the skills from a number of disciplines, often requiring a biophysical team. It is difficult to find qualified research scientists who understand the construction and operational aspects of a project as well as remote sensing techniques.

Mutch, W. E. S. 1974. Land Management--An Ecological View. J. Environ. Mngt. 2:259-267.

The model of land use decision making as a simple sequence of ecologist: economist:politician-administrator is rejected as both unrealistic and theoretically unsound. The ecologist generally lacks precise knowledge of the production functions and of the stability in the systems he confronts; he is unable to determine what is feasible in management unless and until he knows the capital and labour resources that might be allocated to the system. It is characteristic of managed systems that they offer progressively less multiple use, and that they lose diversity and inherent stability, as intensity of management increases. Reference is made to the difficulty and costs of applying artificial controls to replace the lost checks provided by natural diversity.

Parker, H. Dennison. 1975. Remote Sensing for Western Coal and Oil Shale Development Planning and Environmental Analysis. In: Remote Sensing, Energy-Related Studies, T. Nejat Verziroglu, ed. Hemisphere Publishing Company. Washington, D. C. p. 171-187.

There are two broad categories of application of remote sensing technology in the development of fossil fuel resources in the western U.S. The first includes pre-construction site evaluations, land use and usability mapping, and environmental baseline data acquisition. The second category involves long-term environmental monitoring. The geographic magnitude of these developments, particularly when multiple mines or processing plants are considered on a regional scale, precludes the use of conventional ground-based analysis techniques. The time frame in which these resources must be developed also limits the utility of conventional methods. This paper will discuss both categories of remote sensing applications and the overall role that remote sensing can play in furthering the national goal of major dependency on internal sources of energy.

Sievering, Herman, and James Sinopoli. 1976. A Framework for Regional Environmental Management. J. of Environ. Mngt. 4:141-147.

A framework for environmental decision-making is described in which both qualitative and quantitative aspects of regional problems can be integrated into a problem-solving context. The techniques employed in this framework are computer simulation, games, and vote-trading. The paper concludes that through this framework: (a) environmental analysts can assess public value structure goal sets which can be used in the development of regional simulations, and (b) in turn, the quantitative aspects of the problems will be more easily communicated to the affected public. A brief description of the application of the framework is also presented.

Smith, D. W., R. Suttling, D. Stevens, and T. S. Dai. 1975. Plant Community Age as a Measure of Sensitivity of Ecosystems to Disturbance. J. of Environ. Mngt. 3:271-28.

The method outlined, based on sound ecological principles, provides an objective evaluation of the ecological cost of human activities in natural ecosystems. The "cost" is judged in terms of the potential time needed to replace destroyed terrestrial vegetation. The approach involves, firstly, the development of a classification for all terrestrial vegetation types within a region of study. However, an existing classification may be used, when necessary, modified to suit the purposes desired. Secondly, after the major types are identified, they are assigned an ordinal rating which is proportional to their age of development. Finally, once a study region has been evaluated the fractional area of each class is multiplied by its rating and the products are summed for any given unit area, e.g. $2^2$ kilometers. The later information, which defines the ecological sensitivity of a region on a unit area basis, can be mapped and thus provide a sound basis for land-use planning decisions. While the method provides an objective evaluation of the landscape it is recognized that other criteria must also be considered in making any comprehensive planning proposals.

Sondheim, M. W. 1978. A Comprehensive Methodology for Assessing Environmental Impact. J. Environ. Mngt. 6:27-42.

A methodology for assessing environmental impact is developed and tested. Advantage of this technique over other methods include: the ability to evaluate simultaneously a large number of project alternatives; the capability of incorporating directly a very broad definition of "environment" in the assessment process; the segregation of the subjective components of the study; the possibility of including direct public participation in the assessment process; the use of interval or ratio rating schemes instead of ordinal ones; and the examination of specific potential impacts in the way(s) deemed most suitable. The methodology was devised in response to a problem involving whether a dam should be constructed at a given site; however, it should be noted that the methodology is applicable to a wide variety of situations.

Terborgh, John. 1975. Faunal Equilibrium and the Design of Wildlife Preserves. In: Ecological Systems, F. B. Galley and E. Medina, eds. Springer-Verlag, New York. p. 369-380.

A recurrent theme in science is that the utilitarian harvest from new theoretical developments comes after some delay and often in unanticipated quarters. So it can be said of modern island biogeography whose founders, MacArther and Wilson (1963), perceived the simplicity and analytical tractability of isolated ecosystems. Now it is becoming increasingly apparent that the methods and the way of thinking they developed are extensible to a much larger range of situations, including the design of faunal preserves.

The author's own experience has been largely with birds; while the arguments presented in this book pertain especially to them, there is no evident reason why the principles should not apply equally well, with appropriate modification, to other groups of animals. This presentation is organized into three sections. First, evidence is considered that tropical forest bird species, with few exceptions, have very limited dispersal and colonization abilities in relation to their temperate counterparts. Second, an examination is made of the kinetics of species loss on a forested island cut off from the normal interchange with adjacent forested regions. Last, the conclusions to be drawn from these results are applied to the problem of how to optimize the design of faunal preserves.

Tueller, Paul T., and D. Terry Booth. 1975. Large Scale Photograph for Erosion Evaluations on Rangeland Water Sheds in the Great Basin. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 708-753.

The practicability of using vertical, aerial photography to inventory erosion conditions on arid and semiarid range water sheds in the Great Basin has been determined. Established erosion movement transects resulted in the assurance that large scale (1:600) 70 mm sequential color photographs in stereo pairs can be used to detect and inventory soil movement. Soil surface factors which lend themselves to evaluation of erosion were flow patterns, wind erosion, litter movement, vesicular horizons, bare ground, rills and gullies. Ground observations were compared with photographic data to develop descriptions, keys and guidelines for the interpretation of each erosion condition. Specific examples of each soil surface factor have been developed. Photo evaluations on these large scale photographs were found to be as accurate and less costly than ground techniques. Costs involved in flight time and interpretation averaged less than $0.025/h ($0.01/acre).

Warner, M. L., and D. W. Bromley. 1974. Environmental Impact Analysis: a Review of Three Methodologies. Technical Report. Institute for Environmental Studies, Departments of Forestry and Agricultural Economics, and Water Resources Center. Univ. of Wisconsin-Madison, Madison, Wisconsin. p. 65.

The National Environmental Policy Act of 1969 (NEPA) required the filing of environmental impact statements by Federal agencies proposing major actions significantly affecting the quality of the human environment. This research suggests bases for the evaluation and further development of methodologies used to prepare impact statements. Three methodologies are critically analyzed. There are: the "Leopold approach," suggested by Luna B. Leopold, et al. (1971), the "Battelle approach," developed at Battelle's Columbus laboratories for the U.S. Bureau of Reclamation (Dee et al. 1972), and the "WRC approach," contained in the "Principles and Standards for Planning Water and Related Land Resources" of the U.S. Water Resources Council (1973). Specific criteria for methodology evaluation are developed within the areas of: technical ecological content, practical applicability, and political utility. These criteria are designed to emphasize a "full-disclosure law" interpretation of NEPA. The methodologies are examined using each set of criteria in turn. To provide a more concrete setting for this analyst, a test case involving a proposed U.S. Bureau of Reclamation water resources development project in Southwest Idaho was used. Data collection consisted of a point-by-point comparison and related desirable characteristics to each methodology. These data are analyzed for overall methodological conformance to the criteria to yield conclusions on the strengths and weaknesses of the methodologies.

*Wetland Use in Wisconsin.* Present Policies and Regulations. Wisconsin Department of Natural Resources. Madison, Wisconsin. p. 24.

This report is one of a series of reports written for the Statewide Water Resources Plan, Visions of Tomorrow. Phase one of the plan was published in November 1973. The purposes of the Plan are to: (1) describe water resource management alternatives; (2) examine the tradeoffs associated with each; (3) solicit people's preferences with respect to the alternatives; (4) present this information to decision makers; and (5) publish the decision makers' choices, which in effect become the plan. A previous publication, *Wetland Use in Wisconsin: Historical Perspective and Present Picture*, provided a historical analysis of wetlands and wetland use in Wisconsin. This report presents an overview of the mosaic of policies, regulations and laws which apply to these wetlands. Both reports were written to provide background information needed in consideration of alternative futures, policies and regulations for the use of the state's wetlands.

Wright, Colin. 1974. Some Political Aspects of Pollution Control J. of Environ. Econ. and Mngt. 1:173-186.

In this paper some principles of optimal control theory are applied to an examination of the posible differences that political and economic decisions making may have in the area of pollution control. The main points are that (1) Pollution Control Boards (PCB's) may behave as though they place weights on control and benefit functions that differ from market determined weights,

(2) divergencies between political and market weights impose welfare losses, and (3) given that PCB's may be succeeded by another board the current PCB may adapt its behavior to counteract or enforce the expected future behavior of the new PCB.

Wynn, S. L., and O. L. Loucks. 1975. A Social and Environmental History of Parfrey's Glen. Trans. Wisconsin Academy of Sciences, Arts and Letters. 53:26-53.

The social and environmental history of Parfrey's Glen, and the evolution of its management as a natural area, are traced over the past 120 years. Studies of the impact of visitors on the Glen, particularly on the vegetation, were carried out to evaluate recreational carrying capacity. A procedure using a Disturbance Index was developed to measure the degradation in vegetation on upland habitats in the Glen, measured between June 1970 and September 1971. Results indicate that the relatively undisturbed vegetation near the trails is being degraded rapidly, while areas that are already so damaged as to preclude further deterioration show no recovery. Results also suggest that if the Disturbance Index were determined annually it would show whether the vegetation is recovering under new management practices. Guidelines for management policies in sensitive natural areas such as Parfrey's Glen are offered to allow public access but allevaite the impact of human use.

## LAND USE CLASSIFICATION SYSTEMS

Anderson, James R., Ernest E. Hardy, and John T. Roach. 1972. A Land Use Classification System for Use with Remote-Sensor Data. Geological Survey Circular #671, update now called Geol. Survey Professional Paper 964.

The framework of a national land use and land cover classification system is presented for use with remote sensor data. The classification system has been developed to meet the needs of Federal and State agencies for an up-to-date overview of land use and land cover throughout the country on a basis that is uniform in categorization at the more generalized first and second levels and that will be receptive to data from satellite and aircraft remote sensors. The proposed system uses the features of existing widely used classification systems that are amenable to data derived from remote sensing sources. It is intentionally left open-ended so that Federal, regional, state, and local agencies can have flexibility in developing more detailed land use classifications at the third and fourth levels in order to meet their particular needs while at the same time remaining compatible with each other and the national system. Revision of the land use classification system as presented in U.S. Geological Survey Circular 671 was undertaken in order to incorporate the results of extensive testing and review of the categorization and definitions.

Doverspike, George E., Frank M. Flynn, and Robert C. Heller. 1965. Microdensitometer Applied to Land Use Classification. Photo. Eng. 41:294-306.

The fundamental acquisition of land use data from aerial color photographs would be expedited if the process could be automated. However, color density alone does not seem to offer a solution to differentiate land use on the photographs. Although aperture size affected density readings, no improvement in land use discrimination could be ascribed to the aperture area. Moreover, the geometric shape of the microdensitometer aperture (circular, slit or square) was of little or no significance. Density differences in the blue region of the spectrum offered more possibilities in separating ten land use classes than did the red or green.

Frazier, Bruce E., and Gerhard B. Lee. 1975. Effectiveness of a Computer Land Use Planning System Utilizing Generalized Data. In: Proceedings of the Am. Soc. of Photogrammetry Fall Convention. Phoenix, Arizona. p. 754-777.

Computerized land use planning systems, developed by governmental and private entities, have proliferated in recent years. This investigation of the capabilities of one such system for locating linear tracts of land in an agricultural region (e.g., highway corridors) also evaluates the usefulness of generalized soil survey information in conjunction with other remotely sensed data.

Spatial computer models were applied to an area in eastern Wisconsin. Generalized data included soil associations, land cover, slope, and land use stored by 1/9 km cells. Models were constructed to represent land use ideas supported by various sectors of society. Routes were automatically selected by each model and plotted on a medium intensity soil map to test their effectiveness in avoiding prime agricultural land.

In an area that was mainly classified in USDA capability classes I and II (85%), routes selected by the various models included from 46% to 86% classes I and II land. Other tests indicated improvements in model performance with increasing length. Subtle differences in models provided significantly different route locations within 17 km. Major difference in models showed significantly differnt locations within 6 km.

Kiefer, R. W., and M. L. Robbins. 1972. Computer-Based Land Use Suitability Maps. Paper presented at the 1972 Am. Soc. of Civil Eng. Annual and National Environmental Engineering Meeting. Houston, Texas. 38 p.

A computer-based method for generating land use suitability evaluations for urbanizing areas is presented. These evaluations are based on an analysis of the physical characteristics of land, such as topography, soil class, soil drainage, flood hazard, and depth to bedrock. This method allows a great deal of flexibility in analysis and provides the ability to look at land use suitability from a variety of viewpoints or development policies. The use of this computer-based system to prepare residential land use suitability from a variety of viewpoints or development policies. The use of this computer-based system to prepare residential land use suitability maps for a 59.5 $km^2$ area containing 5,950 one-hectare data cells is illustrated. Such a method could be a powerful planning tool when used in conjunction with an evaluation of the other social, economic, political, and environmental factors that shape the patterns of urban development.

## DATA ANALYSIS INFORMATION

References discussing diversity indices, association analysis, crosstab capability, minitab capability, geographic information systems, data available from high platform remote sensors, sampling and summarizing data for plant community classification.

Allen, T. F. H., and J. F. Koonce. 1973. Multivariate Approaches to Algal Stratagems and Tactics in Systems Analysis of Phytoplankton. Ecology 54(6):1234-1246.

Numerical classifications and principal components ordinations were performed on species from 57 weekly samples of phytoplankton from Lake Wingra. The data were considered in absolute and relative terms before and after transformation to presence/absence and logarithmic quantities. The data were also analyzed, taking into account growth rates in the samples, by means of a transformation that replaced the scores of species present by the productivity of the sample as determined by C uptake/biomass. It is shown that different transformations can reveal different but biologically meaningful aspects of the data. These different biological aspects are species similarities based on either short-term survival expedients in particular environmental circumstances, species tactics, or long-range growth patterns involving breadth of tolerance and place in the community, that is, species strategems. Most phytoplankton species in Lake Wingra adopt one of three stratagems: either ungrazed, slow-growing and very persistent, or ungrazed, fast-growing and of intermediate duration, or grazed fast-growing and ephemeral. Tactical information is relevant to particular systems, while strategic information is needed in ecosystem comparison and for models applicable to several systems.

Allen, T. F. H., and S. Skagens. 1973. Multivariate Geometry as an Approach to Algal Community Analysis. Br. Phycol. J. 8:267-287.

Multivariate analyses are put in the context of more usual approaches to phycological investigations. The intuitive common-sense involved in methods of ordination, classification and discrimination are emphasized by simple accounts which avoid jargon and matrix algebra. Warnings are given that artifacts result from technique abuses by the naive or over-enthusiastic. An analysis of a simple periphyton data set is presented as an example of the approach. Suggestions are made as to situations in phycological investigations, where the techniques could be appropriate. The discipline is reprimanded for its neglect of the multivariate approach.

Bartell, S. M., T. F. Allen, and J. F. Koonce. Ordination of Community Structural Dynamics in Lake Wingra Phytoplankton. Memo report for internal use in the U.S.-I.B.P. Eastern Deciduous Forest Biome Program. 35 p.

We use a multivariate analytic approach to describe compositional changes and structural dynamics of the Lake Wingra phytoplankton. Principal component analysis ordinates temporal changes in species composition in samples collected regularly from March 1970 through August 1973. The analyses allow us to track a "community particle" as it moves in a species dimensioned space through time. Community trajectories based upon data averaged over three sample depths (surface, 1, and 2 meters) indicate two compositionally stable periods (winter and summer) separated by spring and autumnal transition periods when composition changes rapidly. While some positive correlation exists, the spring transition is not merely the reversal of the autumn compositional changes; each transition is distinct. We examine nine physiochemical parameters for causal mechanisms underlying observed trajectory behavior. Single parameters are correlated with loadings of samples on individual axes. More importantly, we correlate community behavior to changes in a complex environment.

Bryant, N. A., and A. L. Zobrist. 1979. IBIS: A Geographic Information System Based on Digital Images Processing and Image Roster Data Type. In: Symposium Proceedings Machine Processing of Remotely Sensed Data, LARS. West Lafayette, Indiana.p.69-73.

There is a pressing need for geographic information systems which can manage spatially-referenced data, that perform certain types of spatially-oriented processing, and that are current and comprehensive. Polygon overlay and grid cell information systems access data for selected areas, but their data files are time consuming to generate and frequently costly to process. Updating of land use changes for such systems may become prohibitively expensive. In response to the present dilemma, a system is presented that makes use of digital image processing techniques to interface existing geocoded data sets and information management systems with thematic maps and remotely sensed imagery. The basic premise is that geocoded data set can be referenced to a roster scan that is equivalent to a grid cell data set.

Several technical problems have been overcome to achieve a workable system. First, digital image file handling, image manipulation, and image processing capabilities must be provided. Second, image data must be registered or indexed to spatially-referenced tabular data so that processing steps which involve both types can operate. Third, a data interface must be provided between the different data types so that the results of processing can be represented. Finally, image processing analogs must be developed for existing geo-base file computational steps (e.g., overlay, aggregation, cross tabulation, etc.). The system is now in use on a test basis.

Crossman, John S., Roger L. Kaesler, and John Cairns, Jr. 1974. The Use of Cluster Analysis in the Assessment of Spills of Hazardous Materials. The Am. Midland Naturalist 92(1):94-114.

The macrobenthic community of the Clinch River, near Carbo, Virginia, has twice been subjected to acute stress caused by major industrial spills from a power plant. The first spill, which resulted in a high pH shock, was from a fly-ash retaining pond in 1967. The second was an acid spill in 1970 with consequent low pH stock. Stream surveys were made in 1969, 1970 and 1971. This paper reports the results of Q-mode cluster analysis of presence-absence data on the total aquatic insect fauna, several orders of insects considered separately, and *Gastropoda* from those surveys.

Recovery from the effects of the fly-ash spill by all elements of the fauna studied except the *Gastropoda* was well underway by the summer of 1969. Nevertheless, the insect fauna in samples from the area affected by the spill was still different from that in unpolluted reaches of the stream although it was not possible to discriminate between remnant effects of the spills and chronic stress due to the day-to-day operation of the power plant. The spill of acid in 1970 eliminated many elements of the fauna from about 30 km of the river. Again, by the end of the summer recovery was well underway for all groups, except *Gastropoda*. Cluster anaysis was particularly useful in determining the effects of type of substrate, time of sampling, longitudinal succession, and flooding on the composition of the macrobenthic community. It is suggested that one effect of flooding may be to make the fauna more monogeneous so there is a more nearly equal distribution of macrobenthic organisms among the stations from which samples were collected.

Gauch, Hugh G. Jr., 1973. The Relationship Between Sample Similarity and Ecological Distance. Ecology 54(3):618-622.

Similarity measures for samples from natural communities show a complex, curvilinear decrease with increasing separation of samples along environmental gradients. The form of this decrease for samples without sampling errors has been analyzed and found to be a complement of a non-standardized error function for percentage similarity, and similar functions for coefficient of community and Euclidean distance. For samples affected by sampling error, altered and somewhat flattened curves result. These relationships are important in many ordination techniques. In particular it is demonstrated that Bray-Curtis ordination can be improved by application of the inverse function transforms with moderate beta diversity (up to 5 half-changes). Such transforms produce similarity measures which are linear with respect to separation along the gradient, up to the point beyond which samples have practically no species in common and similarity measures of any sort are consequently meaningless.

Gilmer, David S., Steven E. Miller, and Lewis M. Cowandin. 1973. Analysis of Radiotracking Data Using Digitized Habitat Maps. J. Wildlife Mngt. 37(3):404-409.

A method is described that provides a rapid and accurate analysis of habitat used by radio equipped animals. The digitizer (basically an X-Y plotter in reverse) converts maps into digital formats describing each habitat unit as a polygon that closely approximates the actual shape of the unit. The coordinates of each polygon are then stored on magnetic tape. Habitat classification data and other information are coded and combined with the proper polygon coordinates. This results in one file containing all habitat data. A computer program with inputs of tracking data and habitat data provided a listing of the habitat used by the animals studies. Analysis of habitat used by radio-equipped ducks is demonstrated using this method.

Green, Roger H. 1974. Multivariate Niche Analysis with Temporally Varying Environmental Factors. Ecology 55(1):73-83.

Data consisting of samples of species' presences in association with measurements on a set of environmental variables can be used to determine environmental factors separating the species. If the multiple discriminant model is modified by a covariance extraction of time effects applied to the within-species, and total deviation squares and cross products matrices prior to the discriminant analysis, then temporally varying environmental parameters can be included. If the distribution of sampling in space is consistent over time, then factors separating the species in time, as well as in space, can be determined; if it is not, then separation in space can still be determined even if the samples were collected at different times. The multiple discriminant model is analogous to the Hutchinsonian niche model: its use is illustrated with artificial data, and it is then applied to data from a benthic stream community to demonstrate heterogeneity of niche sizes, and separation of species' niches in space and in time by different environmental factors related to substrate type and water depth. Trophically similar species are more environmentally separated than are trophically different species; the separation is spatial for herbivore-detritivores, and temporal for carnivores.

Green, Roger H. 1971. A Multivariate Statistical Approach to the Hutchison Niche: Bivalve Molluscs of Central Canada. Ecology 52(4):543-556.

The use of multiple discriminant analysis to identify the significant and independent ecological factors separating species distributions is proposed and discussed. Such an analysis was performed on 345 samples containing a total of 10 bivalve molluscs species from 32 lakes in Manitoba, Ontario, and Saskatchewan. Measurements of nine ecological parameters were associated with each sample. Five discriminant functions account for 95% of the among-species variance, and 40 of the 5 are ecologically interpretable. Three of these, accounting for 80% of the among-species variance, are interpreted as bases of trophic, rather than physical or chemical, separation. There is separation of species on each discriminant function. The use of discriminant score to classify lakes with maximum relevance to species distributions is demonstrated and discussed. A generally applicable measure of environmental heterogeneity based upon this type of analysis is proposed. The value of this type of analysis in quantifying ecological concepts derived from the Hutchinson niche model is discussed. An example is given of a reduced available niche resulting in the loss of two species, smaller realized niches for the remaining species, and greater niche overlap.

Hughes, Roger N., D. L. Peer, and K. H. Mann. 1972. Use of Multivariate Analysis to Identify Functional Components of the Benthos in St. Margaret's Bay, Nova Scotia. Limnology and Oceanography 17(1):111-121.

Trends in the frequencies of occurrence of polychaetes and echinoderms in St. Margaret's Bay, Nova Scotia, were isolated by principal components analysis and cluster analysis. Five principal components accounted for 70% of the total variance, three of them (46% of the variance) associated with sediment type, and one (16% of the variance) with distance from the head of the bay, probably with tidal water movements. The largest component of variance (23%) was due to the difference between fauna from clay (characterized by *Pectinaria hyperborea* and *Synapta* sp.) and fauna from more heterogeneous, coarser sediments. It was concluded that the large, contiguous area of soft mud in the deep part of the bay supports a reasonably well-defined, integrated community.

Hughes, R. N., and M. L. H. Thomas. 1971. Classification and Ordination of Benthic Samples from Bedeque Bay, an Estuary in Prince Edward Island, Canada. J. on Life in Oceans and Coastal Water 10:227-235.

An attempt was made to identify the causes of the distribution of benthos within Bedeque Bay using multivariate techniques programmed for the computer. Both classification by a hierarchical cluster analysis, and ordination by principal components analysis suggested that a large proportion of the variance in the data was directly or indirectly correlated with a salinity gradient. Classification divided the species into two main groups: (a) in the upper half of the estuary where lower salinities and larger salinity fluctuations occurred, and (b) in the lower half of the estuary with a more stable salinity regime. The group b species were further subdivided into those preferring soft mud and those preferring sandier sediments. The group a species were divided into a well-developed oyster association and various sub-groups less strongly associated with oysters. Five principal components were required to account for 50% of the variance in the data. The first axis accounted for 20% of the variance and was shown by a non-parametric test to be correlated with the salinity gradient. Axes II to V could not be interpreted, but possibly represented complex species interactions. By providing hard substrates and altering the nature of the sediment, oysters and mussels produced conditions suitable for many other species.

Niemann, Bernard, J. Jr., X. A. Bonilla, S. R. Brun, and R. A. Rose. 1975. Rural Landscape Assessment: A Comparative Evaluation of High Platform Remote Sensors. Dept. of Interior, BOR and College of Agricultural and Life Sciences, University of Wisconsin-Madison, Madison, Wisconsin. 243 p.

The investigation consisted of comparing and evaluating high altitude color infrared photography (1:120,000) LANDSAT 1 Paper Products (1:250,000) and LANDSAT 1 false color enhanced images with conventional resource assessment results. The comparison included the use of computer assisted geographical sampling and cluster analysis techniques. The comparative results indicate that high altitude color infrared photography is quite comparable with conventional assessment methods both in time and replicability. LANDSAT results compared with conventional methods are not as effective but much less time is required to obtain results. Good results were obtained from LANDSAT in the measurement of river character.

Ohman, Lewis F., and Robert R. Ream. 1971. Wilderness Ecology: a Method of Sampling and Summarizing Data for Plant Community Classification. N. Cent. Forest Exp. Sta. St. Paul, Minnesota. 14 p.

Presents a flexible sampling scheme that researchers and land managers may use in surveying and classifying plant communities of forest lands. Includes methods, data sheets, and computer summarization printouts.

Ryan, T. A., B. L. Joiner, and B. F. Ryan. 1976. MINITAB Student Handbook. Duxbury Press, North Scituate, Massachusettes. 341 p.

MINITAB: Student Handbook is used with Minitab, a computing system developed to relieve students of the computational drudgery usually associated with statistics. Minitab includes descriptive statistics, simulation, binomial and polynomial distributions, the normal distributions, one sample confidence intervals and tests for population means, comparing two means, correlation and regression, analyses of variance, chi-square tests and contingency tables, and non-parametric statistics.

Swan, J. M. A. 1970. An Examination of Some Ordination Problems by Use of Simulated Vegetational Data. Ecology 51(1):89-102.

Hypothetical vegetation models were made to simulate numerical changes in species populations along a single environmental gradient. A single ordination procedure was evaluated by its ability to detect the ecological information in the hypothetical models. The procedure was successful when the data were drawn from a short length of the gradient but became progressively less so as longer lengths of the environmental gradients were included in the data. This parallels an increase in the number of stands from which each species is absent in the total data set. Zero values appear to mask ecological information, and an intuitive method of assigning "degree of absence" values to the data is described. After this adjustment, ordination patterns were easier to interpret because ecological information was concentrated in fewer axes.

Schubert, J. S., and J. Thie, and D. Gierman. 1977. Computer Processing of LANDSAT Data as a Means of Mapping Land Use for the Canada Land Inventory. In: The Fourth Canadian Symposium. Quebec, Canada. p. 268-281.

Monitoring of land use activities is essential for the design and modification of land use policies, plans and regulations. To facilitate the measurement of land use changes, the Lands Directorate, Environment, Canada, is supporting and carrying out research to assess the usefulness of satellite remote sensing for mapping and updating Canada Land Inventory land use information.

Methods for computer processing of LANDSAT data were compared for identifying areas in northern Alberta where changes in land use have occurred. The source data were land use maps generated from data stored in the Canada Geographic Information Systems. Surface cover classes were separated on autumn LANDSAT data. These classes related well to land uses as defined by CLI for the stored source data. Recent changes in land use were observed during field study and were successfully classified and mapped using computer-processed LANDSAT data.

Visual classification of images generated by computer was far superior to the three computer classification methods tested: supervised and non-supervised interactive methods and a new automatic method implemented for this study at Lands Directorate. While the computer methods were not significantly different in classification accuracy, the new automatic method was least expensive.

Seigal, Sidney. 1956. Non-Parametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, New York. 312 p.

This is a reference book on the use of non-parametric statistics. It covers the one sample case, the case of two related samples, the case of two independent samples, the case of k related samples, the case of k independent samples and measures of correlation and their significance.

Wishart, D. 1970. Clustan IA User Manual. Computer Laboratory, University of St. Andrews, St. Andrews, Scotland. 118 p.

This is a manual which describes a set of Fortran IV programs designed for the collective study of several methods of cluster analysis and other multivariate procedures. The emphasis throughout the development of this package has been to simplify program specifications so that routines are easy to use but still offer many non-standard options.

White, E. J., and D. K. Lindley. 1976. The Reduction of Climatological Data for Ecological Purposes: a Preliminary Analysis. J. of Environ. Mngt. 4:161-182.

Principal component analyses were carried out on records from the Moor House Climatological Station, as a preliminary to analysing data from many stations distributed over the United Kingdom, and, subsequently, to relating climate to plant response. The use of daily data, with the Penman estimate of evapotranspiration added, was compared with the use of 5-daily, monthly and quarterly means, for 1960 to 1969 inclusive. The first five components generally expressed temperature or energy, dampness, windiness, snowfall and windiness respectively, and acounted for 81 to 93% of variability. It was considered that quarterly means were a suitable basis for future calculations. The stability of the analyses resulting from different sets was compared. Selection of the variables was discussed, and while it is possible to select variables by the importance they have as sources of variation with the meteorological data, their relative importance in explaining response by any one plant or animal will not be known until such response has been measured and relationships with meteorological variables have been assessed.

## MISCELLANEOUS

Baldwin, Helene L., and C. L. McGuinness. 1963. A Primer on Ground Water. U.S. Dept. of Interior, U.S. Geological Survey, N.O. G.S. 64-160. 25 p.

This primer defines ground water and where and how it is found, tells how ground-water quality is defined, and describes wells and their impact on ground water. Lastly it discusses managing water resources. This primer is a good place to start for persons who know nothing about hydrology.

Bell, David T. 1974. Tree Stratum Composition and Distribution in the Streamside Forest. The Am. Midland Nat. 92(1):35-46.

The woody vegetation of the streamside forest in Robert Allerton Park, Piatt Co., Illinois, is described in relation ot the distribution of river level frequencies of the Sangamon River. The habitats most frequently flooded are dominated by *Acer saccharinum*. With decreasing flooding frequency, dominance is transferred to *Celtis occidentalis* and *Quercus imbricaria*. The areas experiencing no flooding are dominated by *Q. alba*. Changes in the vegetational structure at elevational increments of 0.304 m (1 ft) are discussed. The principle that communities change gradually along environmental gradients is illustrated in a vertical elevation of less than 4 m.

Bormann, F. H., T. G. Siciama, G. E. Likens, and R. H. Whitaker. 1970. The Hubbard Brook Ecosystem Study: Composition and Dynamics of the Tree Stratum. Ecol. Monographs 40(4):373-380.

The synecology of tree species was studied in a mature second-growth forest in the Hubbard Brook ecosystem. The forest, on a 13-ha undisturbed watershed ecosystem covering a 245-m range of elevation, has a basal area of about 23 $m^2hs^{-1}$. Dominance is shared by *Acer saccharum, Fagus grandifolia,* and *Betula alleghaniensis*. Direct gradient analysis and regression analysis indicated a strong response in both stand and species characteristics to an elevational complex gradient. Sugar maple shows a decreasing trend; balsam fir, paper birch, and mountain ash show increasing trends. Beech, red spruce, mountain maple, and striped maple show intermediate patterns. Seedlings and saplings respond to the elevational gradient as do larger trees; however, the behavior of trees, seedlings and saplings of the same species is clearly different. The Hubbard Brook ecosystem is located in relation to the vegetational zonation systems of earlier authors. The only generally agreed upon vegetational boundary, ca. 760 m (2,500 ft), is accounted for by a steepened rate of environmental change in the vicinity of that elevation. Various lines of evidence indicate that the present second-growth forest at Hubbard Brook approximates old-age mature northern hardwood forest. Therefore, the biogeochemical, productivity, and ecological data obtained from this study are representative of a mature ecological system in dynamic balance with regional and local controlling factors, e.g., climate, geology, and topography.

Brown, Jerram L. 1964. The Evolution of Diversity in Avian Territorial Systems. The Wilson Bul. 76(2):160-169.

What are the conditions which facilitate or hinder the evolution of territoriality? No generally accepted solution to this problem has yet been found--perhaps because too specific an answer has been sought for too general a question. Instead, the diversity of systems of territorial and other aggressive behavior has come to be well appreciated, as evidenced in recent reviews of territoriality (e.g., Kuroda 1960, Carpenter 1958, Hinde 1956) and the impossibility of providing a specific answer applicable to all types of territoriality is now realized.

Arguments continue, however, over which selection pressures are the primary factors influencing the development of certain types of territoriality. This continuing dialogue can be observed in the recent contributions bearing on the "function" of territoriality by Peters (1962), Wynne-Edwards (1962), Kuroda (1960), Kalela (1958), Stenger (1958), and others.

The present paper offers a new orientation to the problem by presenting a general theory for the evolution of territoriality with special reference to its diversity among species. Since most of the previous theories have already been shown to be untenable or severly limited (see especially Carpenter 1958, Tingergen 1957, and Hinde 1956, for criticism of them), little attention will be given to them here.

Chatterton, W. A., J. L. Clapp, E. F. Epstein, and B. Niemann, Jr. 1977. Incremental Implementation of a Modern Multi-Purpose Cadastral System. In: Proceedings of the 43rd Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 694-709.

An examination of the land information situation in the United States indicates that efforts to generate an adequate system exists in all stages, at all levels of government in a variety of agencies in both the public, semi-public, and private sector. One dominant charateristic of their ongoing efforts is that they tend to serve a single purpose and have not developed adequate institutional and conceptual mechanisms to take advantage of the common spatial base required for geographically related land information.

The development of multi-purpose cadastres which will meet the land information needs must be based upon a geometric framework adequate to meet requirements at the individual parcel level. This type of framework is essential (1) because these requirements are the most demanding with regards to scale, accuracy, and to the representation of proprietary interests; and (2) because it is possible to aggregate information from the detailed level to the policy level but not the reverse.

In order to implement modern multi-purpose cadastral systems, incremental approaches which are constrained by the broad object must be developed and followed. These approaches must reflect that a multi-purpose cadastral system is a dynamic mechanism which is characterized by incremental change in the existing system. The goal is a sequence of incremental changes over an extended period of time which will provide maximum service as it evolves and yet preserves future options.

Curtis, John T. 1959. The Vegetation of Wisconsin. University of Wisconsin Press. Madison, Wisconsin. 657 p.

This is a definitive study which establishes the geographical limits and species compositions of the vegetation of Wisconsin as well as describing, as much as possible, the environmental relations of the vegetation communities existing within this state. Although the information presented on forest communities is unsurpassed, the information about wetlands is limited.

Dobbin, James A. 1978. Interpretation of Satellite and Aircraft Imagery for Planning/Design and Management of Marine Parks and Reserves. In: Proceedings of the 44th Annual Meeting of the Am. Soc. of Photogrammetry. Washington, D.C. p. 93-117.

The establishment of marine parks and reserves represents an important new approach for the protection of critical marine ecosystems. Interpretation of remotely sensed imagery could be an effective method for collection, classification, and analysis of resource information for planning and managing marine parks and reserves. This potential was examined in two case studies using Landsat, high and low altitude aircraft imagery, and the technique of density slicing to supplement existing information obtained from ground observations. In both case studies, interpretations revealed important new information and established the value of these techniques for site specific analyses. Landsat imagery could also be a vital tool for a survey team attempting the efficient acquisition of up-to-date data, especially in remote areas, or for the planning of regional systems of marine parks and reserves.

Dolan, R. 1973. Coastal Processes. Photog. Eng. 49:255-271.

Along sandy coasts the configuration of the shoreline is seldom straight, but rather crescentic in plain view. Crescentic forms can serve as indicators of beach and inshore bar-trough relationships, as well as places along the coast where surge and overwash may focus during storms. The increased availability of high-altitude aerial photographs offers, for the first time, a data source for the investigation of crescentic features of sand coasts.

Dunn, Michael C. 1976. Landscape Evaluation with Photographs: Testing the Preference Approach to Landscape Evaluation. J. Environ. Mngt. 4:15-26.

The development of techniques for landscape evaluation is traced and the fundamental differences between measurement and preference methods stressed. The paper then reports the results of a case study which sought to examine public preferences for contrasting landscapes, and to investigate the effectiveness of photographs in representing landscapes.

Gates, David M. 1970. Physical and Physiological Properties in Plants. In: Remote Sensing with Special References to Agriculture and Forestry. Natl. Research Council, Natl. Academy. Washington, D.C. p. 224-252.

The appearance of plants and of vegetated surfaces to multispectral sensors or to the human eye depends on their interaction with radiation. A plant or vegetated surface may be viewed actively by reflected sunlight and skylight or passively by the emission of thermal radiation from the plants.

The precise spectral quality and intensity of plant reflectance and emittance depends on leaf geometry, morphology, physiology, chemistry, soil site, and climate. It is the purpose here to discuss those physical and physiological properties of plants that are significant for multispectral sensing of vegetation. Some description is given of the appearance of vegetation and soils.

Gates, David M., and C. M. Benedict. 1963. Convection Phenomena from Plants in Still Air. Am. J. of Bot. 50:563-573.

The free convection from leaves in still air was observed by means of schlieren photographs of broad-leaved and coniferous trees. A quantitative measure of the rate at which energy was convected away from the leaf was obtained by photographing the size of convection plume, measuring its rate of flow by means of movie photography, and measuring the temperature of the plume with a fine thermo-couple. The heat load on a leaf and the surface temperature of the leaf were obtained with a total hemispherical radiometer and an infrared radiometer respectively. The observations of free convection from broad-leaved plants confirmed the values predicted using heat transfer theory for heated plates. The observations with the branches of coniferous trees gave values which were not readily available from heat transfer theory. The schlieren system can also be used to observe forced convection from plants in wind.

Goff, Glenn F., and Zedler, Paul H. 1972. Derivation of Species Succession Vectors. Am. Midland Naturalist 8:397-412.

By placing size classes of individual species in sequence, within a reference ordination model, a series of succession vectors is produced. These vectors show how the pattern of association of a given species changes in relation to growth. Analysis of data from 879 forest plots in northeastern Wisconsin shows some tree species entering into successional sequences in accordance with existing theory. Other species, particularly those of the zeric sand plains and poorly drained sites, are apparently as self-perpetuating as the traditional "climax" species of mesic sites.

Gurk, Herbert M. 1973. The Need for More Information and Less Data. In: Proceedings of the Am. Soc. of Photogrammetry Symposium of Management and Utilization of Remote Sensing Data. Sioux Falls, South Dakota. p. 513-527.

Higher resolution, more spectral bands and greater frequency of coverge are desires of most users of remote sensor data. Yet the outputs from current observation satellites and aircraft are taxing available facilities and not being fully utilized by potential users. It is acknowledged also that much data being collected may be redundant. Techniques such as data compression, statistical sampling, and mixed-highs multispectral sensing can reduce the data greatly while retaining the important information. Data volume reduction, problems of utilization, and usefulness are discussed for each technique. Experimental results and current programs are presented, and recommendations are made for specific programs.

Hairston, Nelson G. 1959. Species Abundance and Community Organization. Ecology 40(3):404-415.

The organization of natural communities was studied from the standpoint of the relative abundance of the species of microarthropods in the soil of 2 similar communities on a long-abandoned field. An examination of the details of distribution shows a continuous inverse relationship between abundance and clumping of the more than 100 species studied. This observation provides a basis for explaining why various empiricially determined "indices of diversity" are not constant when increasingly large samples from the same community are analyzed. The strong clumping of the rare species means that with increased sampling new rare species are more likely to be added to the total than are additional specimens or rare species already recorded.

In spite of the dependence of the index of diversity on sample size, it can be used to show some interesting relationships, including a crude but completely objective separation of samples from similar communities. It is thus quite useful in situations such as plankton studies where there is no a priori separation of samples on the basis of the appearance of the area from which they came.

The most important use of data of this kind is in MacArthur's model based upon the biological hypothesis that the niches represented by different species abundances are contiguous but non-overlapping. This implies that food determines the abundance of all species, since it is the only factor that is completely utilized and cannot be shared by different species. MacArthur's assumption that the sizes of the niches conform to a random distribution is not confirmed. The departure from randomness is found to be greater with increased sample size as long as the samples come from the same community, but decreases if heterogeneous material is added in the form of samples from another community. These results indicate the degree of organization of the community, since, from information theory, it follows that organization is measured as departure from randomness. The organization of a community results from the outcome of interspecific competition for the available resources, and is expressed both in relative abundance and the spatial distribution of the constituent species.

Hett, Joan M., and Loucks, Orie L. 1968. Application of Life-Table Analyses to Tree Seedling in Quetico Provincial Park, Ontario. Forestry Chronicle. p. 1-4.

Data for numbers of living seedlings by two-year age-classes under old-growth forests permit examination of life-table analysis as a tool for following seedling population relationships. The population depletion curves for white pine, balsam fir and red maple are compared. The negative exponential depletion model is demonstrated as a potentially sensitive method for quantitative comparison of silvical response characterisitcs.

Hough, A. F. 1965. A Twenty-Year Record of Understory Vegetational Change in Virgin Pennsylvania Forest. Ecology 46(3):370-373.

The understory vegetation in a 4,080 acre tract of virgin hemlock-hardwood forest on the Allegheny National Forest, located in northwestern Pennsylvania, was studied over a 20-yr period by means of color and black-and-white photographs taken at 5-yr intervals from 1942 to 1962. The declines which took place in the understory were believed to result from browsing by the resident white-tailed deer population. The deer herd, under very light hunting pressure, has depleted the browse supply and damaged advance reproduction of hemlock and hardwoods, preventing understory recovery during the 1942-62 period. Unless relieved, this continued browsing of the understory vegetation will eventually reduce and endanger the scientific and educational value of the area.

Idso, S. B., and C. T. deWit. 1970. Light Relations in Plant Canopies. Applied Optics 9:177-174.

A theory of light relations in plant canopies is presented which has potential applications in remote sensing and photo-synthetic modeling of plant canopies. Predictions of the model are compared with field measurements of light reflection and transmission in a corn crop. Both reflection at the top of the canopy and transmission at the bottom are predicted within 1% of the measured values. Profiles connecting these upper and lower limits are equally well approximated. Variations in the predictions with altitude angle of the sun are confirmed by the observation of several investigators.

Knight, D. H., and O. L. Loucks. 1969. A Quantitative Analysis of Wisconsin Forest Vegetation of the Basis of Plant Functions and Gross Morphology. Ecology 50(2):219-234.

The structural and functional features of the trees, shrubs, and herbs in the upland forest communities of Wisconsin have been studied for their potential in describing relationships between vegetation and environment. Structure is defined here as the spatial arrangement of the plant biomass, e.g., height, leaf size, and growth form. Functional features include those which are apparent adjustments or responses to the environment, e.g., deciduousness, shade tolerance, method of seed dispersal, and fire resistance. Quantitative estimates of the importance of plant features such as these, regardless of species, were obtained for each of 149 forest stands distributed throughout

Wisconsin in all types of upland forest vegetation. Using the index of similarity, c = 2w/a + b, each of the 149 stands was compared to every other stand on the basis of 29 tree structural-functional features. The spatial relationships in the resulting ordination demonstrate that the upland forest communities can be distinguished and studied using these features. Although adjacent stands in the ordination are smilar on the basis of tree structure and function, they can be different in species composition. The usefulness of grouping species with similar structural-functional features is discussed and related to the concept of ecological equivalence. Finally, the spatial relationships in the ordination are used to derive indices that allow calculation of stand values along structural-functional coordinates. Although the indices are based solely on plant structure, the resulting coordinates can be used to infer some functional features of the vegetation as well as successional status and certain environmental relationships.

Kuchler, A. W. 1973. Problems in Classifying and Mapping Vegetation for Ecological Regionalization. Ecology 54(3):512-523.

Important research carried on currently in ecological regionalization calls for a close look at the role of classifying and mapping vegetation, as both these activities can be of fundamental significance in regionalization. A correlation of classifying and mapping vegetation with ecological regions requires an analysis of vegetation, classifications, regions, and maps.

The analysis of vegetation revealed the character of biogeocenoses, plant communities, and continua and, incidentally, made it clear that the correct term for the science of vegetation studies is phytocenology. Problems of vegetation boundaries can develop when continua are compared with transitions. This is important in mapping where the nature and location of boundaries is of major significance. Vegetation is best divided into natural and cultural vegetation and further subdivided on the basis of (1) physiognomy and structure, (2) floristics, (3) community dynamism, and (4) community relations with their respective biotopes.

When these units were applied to an analysis of classifications, it developed that a basic distinction must be made between highly flexible, purely descriptive and essentially classless approaches on the one hand, and clearly organized hierarchies on the other. Serious difficulties can arise when a detailed description of vegetation is related with a classification, and an important distinction emerging from these findings is between worldwide and regional classifications. Multiple mapping at large scales evolved into a particularly useful and enlightening method.

However, the often demonstrated correlation between phytocenoses and environmental conditions must not lead a researcher to falsely optimistic conslusions, as it may not be applicable in the humid tropics. Aubreville, Poore, Wyatt-Smith, Koriba, Kuchler and Sawyer, etc. have illustrated the need for caution in interpreting such correlations.

An analysis of some aspects of regions demonstrated that the relationships between vegetation types and biotopes must be clarified before meaningful ecological regions can be established. This need was illustrated with the map and inset maps of the Hunter Valley region in New South Wales, which proved most revealing.

The chief problem of maps in ecological regionalization was found to be the map scale. Scale problems can usually be solved without much difficulty, but they must be clearly understood if the results are not to be misleading.

The very nature of the biogeocenose implies by definition that the geographical distributions of biocenoses and of biotope are most intimately related. The various analyses revealed that vegetation may be regarded as a tangible, integrated expression of the biogeocenose. Maps showing the geographical distribution of the natural (or the potential natural) vegetation do therefore and thereby also reveal ecological regions.

Leopold, Luna B. 1968. The Hydrologic Effects of Urban Land Use. U.S. Geological Survey Circular 554. 18 p.

Cities cause local but severe changes in the hydrologic cycle. The pavement and roofs of urbanization greatly increase the percentage of the land's surface which is impervious to water. Rather than infiltrate into the ground, a high proportion of precipitation runs off into streams, causing greater flooding than in the country. Urban land use promotes erosion and produces large quantities of sediment.

Urbanization also decreases the quality of water in two ways. First waste materials, including dissolved solids, pathogenic bacteria, and heat are added to the water. Second, the high flood peaks and low rate of infiltration lower the recharge of ground water, and this descreases the amount of water normally flowing in streams. Hence, there is less water available for such uses as municipal supply and safely diluting discharges of sewage.

Finally, urbanization commonly causes streams to lose their attractiveness. Increased floods cause scoured or muddy stream channels. Trash in the channels adds to the disfigurement. Reduced oxygen content and reduced water flow alter aquatic life and contribute to turbid, slimy, smelly streams.

In this selection Luna Leopold explains and elaborates on these changes. It is interesting to note that despite the considerable amount of research done on urban hydrology, there are many gaps in our understanding. Leopold is one of the few modern scientists to evaluate and quantify the esthetics of landscape (Leopold 1969). Streams flowing through cities, especially, could enhance the quality of urban life if they were properly understood and managed, although the variety and complexity of urban effects on hydrology appear to work against this.

Leopold, Luna B., and Walter B. Langein. 1962. The Concept of Entropy in Landscape Evolution. Geological Survey Professional Paper 500-A. 20 p.

Entropy, a conceptual framework for describing the distrubution of energy in natural systems, is expressed in terms of the probability of various states. The principle of entrophy is based on the concept that when energy in a river system is as uniformly distributed as may be permitted by physical constraints. This represents the most probable conditions that can exist for this natural system. From these general considerations, equations for the longitudinal profiles of rivers are derived that are mathematically comparable to those observed in the field. The most probable river profiles tend toward the condition in which the downstream rate of production of entropy per unit mass is constant. Hydraulic equations are insufficient to determine the velocity, depths, and slopes of rivers that are themselves authors of their own hydraulic geometries. A solution becomes possible by introducing the concept that the distribution of energy tends toward the most probable. This solution leads to a theoretical definition of the hydraulic geometry of river channels that agrees closely with field observations.

The most probable state for certain physical systems can also be illustrated by random-walk models. Average longitudinal profiles and drainage networks that were derived in this fashion have the properties implied by the theory. The drainage networks derived from random walks have some of the principal properties demonstrated by the Horton analysis; specifically, the logarithms of stream length and stream numbers are proportional to stream order.

Lind, Christopher T., and Grant Cottam. 1969. The Submerged Aquatics of University Bay; a Study in Eutrophication. The Am. Midland Naturalist 81(20):353-369.

The submerged aquatic plants of University Bay, Lake Mendota, Dane Co., Wisconsin, were sampled using the line intercept method. Twenty-one lines were set perpendicular to the shoreline so that they extended into the bay to the depth at which submerged aquatic plants ceased to grow. All plants intercepting the line were recorded within consecutive half-meter segments of the line. The data were used to construct a contour map of the vegetated portions of the bay and to delimit the plant communities. Six plant communities were found. Data on plant height and standing crop were obtained from quadrat samples taken at biweekly intervals from four regions with the bay. The data were compared with studies made in 1922. Marked changes in quantitative composition have occurred since 1922, with the most marked difference being the great increase in *Myriophyllum exalbescens* and the complete disappearance of several species that were formerly major components of the vegetation.

Lingenfelter, R. E., and Gerald Schubert. 1973. Remote Sensing of Stream Flow Rates: Correlation of Meander and Discharge Spectra. In: Remote Sensing and Water Resources Management Proceedings No. 17. p. 404-418.

This report describes a basic study of river meander patterns and discharges in which the authors attempeted to correlate the discharge spectrum of a river with the river meander power spectrum determined from aerial and satellite imagery. Such a correlation could provide a technique for remote sensing of the water resources of large geographical areas. Although a large enough number of rivers were not yet studied to attempt a correlation between the discharge and the meander spectra, some significant characteristics of both spectra were discovered. Discharge frequency spectra based on long term records of daily streamflow were found to have an inverse power law dependence on discharge. This is shown to reflect the short term decay of individual floods which are found to have an inverse power law dependence on discharge. This is shown to reflect the short term decay of individual floods which are found to have an inverse power law dependence on time. Meander power spectra for a number of river reaches, digitized from aerial photography, also show significant structure. This type of pwer spetra data, digitized from aerial photography, also shows significant structure since the power spectral density has an inverse power-law dependence on wave number over one or more portions of the spectrum with breaks in the spectra at characteristic wave numbers. A number of examples of typical discharge and meander spectra are shown.

Loucks, Orie L. 1970. Evolution of Diversity, Efficiency, and Community Stability. Am. Zoologist 10:17-25.

The response in species diversity associated with successional change in vegetation, or in a more general sense, species diversity as a function of time in any system of primary producers, has been the subject of much speculation but little direct study. All evidence available shows that pioneer communities are low in diversity, that in mesic environments the peak in diversity in forest communities can be expected 100-200 years after the initiation of a secondary successional sequence (when elements of both the pioneer and the stable communities are present), and that a downturn in both diversity and primary production takes place when the entire community is made up of the shade-tolerant climax species.

The natural tendency in forest systems toward periodic perturbation (at intervals of 50-200 years) recycles the system and maintains a periodic wave of peak diversity. This wave is associated with a corresponding wave in peak primary production. Specialization for the habitats in the early, middle, and later phases of the cycle has figured prominently in species-isolating mechanisms, giving rise to the diversity in each stage of the forest succession. It is concluded that any modifications of the system that preclude periodic random perturbation and recycling would be detrimental to the system in the long run.

MacArthur, Robert H., and Pianka, Eric R. 1966. On Optimal Use of a Patchy Environment. The Am. Naturalist 100(916):603-609.

A graphical method is discussed which allows a specification of the the optimal diet of a predator in terms of the net amount of energy gained from a capture of prey as compared to the energy expended in searching for the prey.

The method allows several predictions about changes in the degree of specialization of the diet as the numbers of different prey organisms change. For example, a more productive environment should lead to a more restricted diet in numbers of different species eaten. In a patchy environment, however, this will not apply to predators that spend most of their time searching. Moreover, larger patches are used in a more specialized way than smaller patches.

Maizell, Robert E. 1960. Information Gathering Patterns and Creativity. Am. Documentation IX:9-17.

A comparison of creative and "noncreative" research chemists with respect to the ways in which they use their professional and technical literature. The creative chemists differ from the "noncreative" in that the former read more technical literature on the job, are less relectant to use literature of greater reading difficulty, are less influenced in their independence of thought, read more extensively and consult more frequently the older material, are more inquisitive and have broader cultural interests. The findings of the study are believed to be helpful in planning library and information services, in refining future inquiries into the ways in which scientists use recorded information, and improving tests for the identification of creative ability among chemists.

Marsden, J. R., D. E. Pingry, and H. B. Whinston. 1976. Environmental Data Management: the Identification of Outliers. J. Environ. Econ. and Mngt. 3:154-163.

Increased emphasis on pollution control and abatement has often necessitated development of large scale data bases. While sophisticated techniques have been developed and employed for data storage and manipulation, parallel developments in analyzing the accuracy and reliability of the data have been absent (see, for instance, the broad spectrum of requirements outlined in the Federal Water Pollution Control Act Amendments of 1972).

This paper centers on the latter and sets out a procedure for data editing and "outlier" identification based on an application of discriminant analysis. A hypothetical example is included along with some suggested applications.

Pianka, E. R. 1966. Convexity, Desert Lizards and Spatial Heterogeneity. Ecology 47(6):1055-1059.

The number of lizard species in the flatland desert habitat is correlated with several different structural attributes of the vegetation. It is shown that both the horizontal and vertical components of spatial heterogeneity are correlated with the number of lizard species. The habits of the twelve component species are considered briefly as they relate to the partitioning of the biotope space. Three species are food specialists, eight display various substrate specificities, and only one species appears to be truly "convex." Two tests of the present interpretation of these results are proposed, and some speculations concerning Austrialian flatland desert lizards are made.

Pakulak, A. J., W. Sawka, and R. K. Schmidt. 1974. Analysis of Nesting Habitat of Canada Geese Using Remote Sensing Imagery. In: Proceedings of the 2nd Canadian Symposium on Remote Sensing. Guelph, Ontario. p. 365-371.

The purpose of this study was to evaluate nesting habitat of Canada geese (Branta canadensis interior) in the Little Seal River area, Manitoba using recent remote sensing imagery. Five different sets of imagery, all taken in August 1972, were carefully examined to determine which films best represented vegetation and landform features. Two types of color infrared photography proved to be most suitable and were used in delineating vegetation-landform (habitat) units on a study area map. These units were then compared with goose nesting data collected in spring, 1970. Canada geese nested in 6 of the 8 designated units but showed a marked preference for birch-willow and gravel ridge habitats. In general, results suggested that remote sensing imagery could be used to describe habitats in other, largely inaccessible goose breeding areas. Such an approach, if applied on a large enough scale, would provide new and relatively, inexpensive ways of estimating annual production of Canada geese in the Eastern Prairie Population.

Simkerloff, D. S., and L. G. Abele. 1976. Island Biogeography Theory and Conservation Practice. Science 191:285-286.

The application of island biogeography theory to conservation practice is premature. Theoretically and empirically, a major conclusion of such applications that refuges should always consist of the largest possible single area can be incorrect under a variety of biologically feasible conditions. The cost and irreversibility of large-scale conservation programs demand a prudent approach to the application of an insufficiently validated theory.

Tans, William. 1974. Priority Ranking of Biotic Natural Areas. The Michigan Botanist 13:31:39.

A detailed description in outline of the priority ranking system of biotic natural areas used by the Scientific Areas Preservation Council of the DNR, Wisconsin is provided. Such a system must be devised so that results among individual researchers will be somewhat similar. The more factors involved in evaluating an area, the more averaging there will be and a simple additive meaningful numerical score for each area is hard to devise since it is a composite score and therefore masks the criminal criteria relating to ultimate preservation by acquisition, availability and threat. The final scoring system decided on retains separate scores for biological and physical characteristics, availability and threat for quick and accurate comparison of areas.

Terbough, J. 1973. Preservation of Material Diversity: the Problem of Extinction Prone Species. Contribution to the American Society of Zoologists Symposium: Toward a System of Ecological Reserves. Houston, Texas. 37 p.

Preserving diversity in a world of rapidly shrinking land resources will require a prompt and universal response based on an appropriate application of ecological knowledge. Every nation should possess an inventory of its biological endowment. Agencies in charge of parks and wildlife should consciously adopt policies that are designed to minimize the pace of extinctions. The common practice of declaring parks in remote or unused portions of the landscape, or around scenic attractions, may fail to serve this purpose. Large reserves are needed to preserve natural vegetation formations, animals at the top of the trophic pyramid, and widespread species with sedentary habits and poor colonizing ability.

Endemics or rare habitat types can frequently be protected with realtively small investment in land, provided appropriate tracts can be identified and sequestered in time. The nesting grounds of colonial species can be spared with even less land withheld from production as they are usually located on offshore islets that are unsuitable for agriculture. Migratory species present more difficult problems since appropriate action often requires international cooperation.